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TERTIARY TREATMENT BY LIME ADDITION AT SANTEE, CALIFORNIA

Howard Almgren

Santee County Water District

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TERTIARY TREATMENT BY LIME ADDITION AT SANTEE, CALIFORNIA,

Almgren, H~~oward~~

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Santee County Water District, Santee, California

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Laboratory and field studies were conducted to evaluate the effect of three tertiary waste treatment processes on the amount of algal growth in the effluent after treatment. The studies included determination of the absolute levels of algal growth under controlled conditions, (Algal Assay Procedure and continuous culture) and comparison with field observations in special study ponds. In addition, determinations of the growth limiting nutrients in each effluent were made. Lime treatment (pH 10.5-11.0) reduced the algal growth potential ten fold. (EPA)

17a. Descriptors

*tertiary treatment, *solids contact process, *chemical precipitations, *filtration, *phosphorus compounds, algal control, reclaimed water, sewage treatment, sanitary engineering, sludge disposal, eutrophication, California, Lime, Activated sludge, *Waste water treatment

17b. Identifiers

*algae assay procedure, ~~advanced waste treatment,~~ *Santee (Calif), recarbonation.

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Howard Almgren	Santee County Water District

EPA-R2-73-206
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Project 17080 EDV

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ABSTRACT

A two mgd tertiary treatment plant for chemical and physical treatment of activated sludge effluent has been built and tested at Santee, California. The plant demonstrated the removal of phosphorus by lime addition and tertiary filtration in a full scale treatment plant operated under typical field conditions. The plant has a design capacity of two mgd.

Total phosphorus removals in the reactor-clarifier were 85 percent with a 60 mg/1 lime dosage (pH 9.5 - 10.0) and 95 percent with 200 mg/1 (pH 10.5 - 11.0). Filtration performance was not satisfactory. The cost of tertiary treatment at 1.5 mgd and 200 mg/1 lime dosage, under steady flow and negligible sludge disposal costs is 16.03 cents per thousand gallons.

Laboratory and field studies were conducted to evaluate the effect of three tertiary waste treatment processes on the amount of algal growth in the effluent after treatment. The studies included determination of the absolute levels of algal growth under controlled conditions, (Algal Assay Procedure and continuous culture) and comparison with field observations in special study ponds. In addition, determinations of the growth limiting nutrients in each effluent were made. Lime treatment (pH 10.5 - 11.0) reduced the algal growth potential ten fold.

This report was submitted in fulfillment of Grant Number WPRD 5-01-67 under partial sponsorship of the Environmental Protection Agency.

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SECTION I

CONCLUSIONS

1. This demonstration project showed that a small sanitary district can build a tertiary treatment plant through regular consulting engineering and bidding procedures and operate it with the usual plant personnel.

2. The removal of total phosphorus in a solids contact reactor-clarifier was 85 percent with a lime (CaO) dosage of 60 mg/l and a pH range of 9.5 - 10.0.

3. The total phosphorus removal in the reactor-clarifier can be increased with greater lime dosage. A removal of 95 percent (resdual of .77 mg/l as P) was obtained with a dosage of 200 mg/l CaO and a pH range of 10.5 - 11.0.

4. A flow of .75 gpm/ft^2 was found to be a reasonable operating upper limit to the flow rate. A flow 1 gpm/ft^2 can be handled but variations in flow easily upset the plant causing a high discharge of solids from the sludge blanket.

5. The rate of addition of lime was found to be satisfactorily controlled by feeding a fixed dosage under steady flow conditions. Automatic pH control did not perform well and was too difficult to maintain.

6. A polyelectrolyte (Nalco 676) dosage of .2 mg/l greatly improved the stability of the blanket. The additional cost was .5 cents per thousand gallons.

7. The addition of single stage recarbonation and dual-media filtration did not improve the phosphorus removal. The removal of suspended solids and turbidity was not satisfactory, perhaps due to poor filter media.

8. The estimated total cost of tertiary treatment for 1.5 mgd (.75 gpm/ft^2 in reactor-clarifier) with a lime dosage of 200 mg/l and filtration is 16.03 cents per thousand gallons. (The cost of sludge disposal at Santee is negligible.)

9. Reliability of equipment was a serious problem in this small plant without dual systems.

10. Under the present circumstances at Santee, with storage lagoons for secondary and tertiary effluent, it is doubtful that the operation of recarbonation and filtration is advantageous.

Algae Growth Study - University of California, Irvine

1. The results of the batch algal assays indicate that the nutrient which limits growth of algae changes as a result of treatment. Thus, it is very important in treatment plant evaluations to conduct parallel algal assays and determine the actual limiting nutrient or nutrients after each process step.

2. The batch algal assays performed in this study showed that phosphate was not the only nutrient limiting growth of the test algae under laboratory conditions. The results indicated that other nutrients especially iron played a significant role in limiting algal growth.

3. Based on the laboratory results, it appears that the question of growth limiting nutrients is very complex and that the concept of a simple limiting nutrient is not valid. Instead, there appears to be several strong positive and negative interactions among nutrients such as nitrogen, phosphorus, iron, manganese, and some of the major cations and anions. It appears necessary to provide further insight into these interactions before a more rational approach to design of nutrient removal processes can be made.

4. On a gross biomass basis, it was found that batch and continuous culture laboratory assays provided the same ranking of effluents from different treatment processes.

5. Using Santee secondary effluent as the basis, the continuous culture algal investigations in the laboratory showed that the lime treatment plus electrodialysis resulted in a 100 fold reduction in the algal growth.

6. Comparison of electrodialysis and ground percolation indicated that at Santee the two processes were approximately equally effective in reducing algal growth as measured by the batch assay test.

7. Two study ponds were built and used to compare the secondary and tertiary effluents. It was found that when the two types of effluent were exposed to the same environment, the tertiary effluent (lime treatment) resulted in less algal growth.

8. The changes in algal growth in the study ponds due to changes in natural conditions such as light and temperature were greater than the difference in growth of algae due to the difference in quality between secondary and tertiary effluents. It is concluded that in future studies, study ponds should preferably be operated over two full years to obtain statistically better results.

SECTION II

INTRODUCTION

A tertiary treatment plant for chemical and physical treatment of activated sludge effluent has been built and tested at Santee, California. This plant was built by the Santee County Water District with partial support from the demonstration grant program of the Environmental Protection Agency. The Santee plant demonstrated the removal of phosphorus and tertiary filtration in a full scale treatment plant operated under typical field conditions. The plant has a design capacity of 2 million gallons per day.

WASTE TREATMENT AT SANTEE

The Santee County Water District, a public agency, provides water and sewer service for an unincorporated community of 20,000 persons. It is expected that the population will increase to about 100,000 by the year 2000. The District encompasses 14,500 acres 20 miles inland from the Pacific Ocean, near San Diego and El Cajon.

In 1959 the San Diego Regional Water Pollution Control Board tightened the discharge requirements applicable to the effluent from the District's existing sewage treatment plant. The Santee community chose not to participate in the Metropolitan ocean disposal plan. Instead it began development of a wastewater treatment system that would produce an effluent higher in quality than that from efficient primary and secondary sewage treatment. Water costs were an important factor in the decision.

A fortunate set of circumstances existed with respect to the location of the existing sewage treatment plant at the lower end of Sycamore Canyon. This is a shallow canyon with gently sloping sides. The canyon bottom is covered with a alluvial fill of sand and gravel approximately 12 feet deep and ranging from 400 to 1,000 feet in width. An impervious clay underlays the sand and gravel.

A sand and gravel company had made previous arrangements with the owner of the canyon lands to mine the sand and gravel from the canyon bottom. The mining operation left the canyon in a despoiled condition but also left behind an excavated area that could easily be shaped into a series of lakes, each having a surface area of 10 to 15 acres.

The proposed treatment scheme was simple. After primary and secondary treatment, the water was given additional treatment by placing it in a lagoon in the excavated area adjacent to the plant. After detention in the lagoon, the effluent was pumped up the canyon to a point about a half mile above the excavated area and there it was put into shallow basins. The water percolated down into the sand and gravel, and because of the underlying clay moved horizontally in the downstream direction until it emerged into an interceptor trench located above the uppermost lake. From the uppermost lake the water flowed from lake to lake in the downstream direction until it was discharged into the San Diego River.

A research program was conducted from 1962 to 1965 oriented especially toward studying possible public health hazards and the public acceptance of reclaimed water (1). The rate of virus removal from the water was a very significant part of this study. The participating agencies were the U.S. Public Health Service, the California Department of Public Health, the San Diego County Department of Public Health, the California Department of Water Resources, the State and Regional Water Quality Control Boards, the California Department of Fish and Game, and the Santee County Water District.

The successful completion of the research program allowed public use of the lakes for boating and fishing and swimming in an adjacent pool supplied with filtered reclaimed water. In addition reclaimed water made possible the construction of a local golf course. This was accomplished for about the same cost as if the community had decided to join the ocean disposal system.

This scheme was not expected to provide a permanent means of reclaiming the wastewater because the sand and gravel in the canyon would eventually be removed by the mining operation. Even if the sand and gravel were not removed, the increasing volume of wastewater to be treated would eventually exceed the hydraulic capacity of the limited percolation area. The important job at the time, however, was to develop a scheme that would provide useable reclaimed water and improve on the working model as operation proceeded. Eventually, as the community grew, the entire treatment capability would have to be compacted into the treatment plant site. The plan developed to accomodate the larger flows included a new conventional plant and a tertiary plant which could replace the lagoon and percolation (2).

In August, 1966, the District received approval of a Federal Water Pollution Control Administration Public Law 660 Grant to assist in the construction of a new 4 mgd primary and secondary treatment plant in Sycamore Canyon. This facility was completed and placed in operation in January, 1968, at a total cost of $2,048,000. It was designed to lead directly into tertiary treatment when that was constructed. For the time being the total flow still passed through the lagoon, percolation area and into the recreational lakes after chlorination.

DEMONSTRATION GRANT

On December 23, 1966, the District received an $800,000 Demonstration Grant from the Federal Water Pollution Control Administration to apply to the cost of construction of an advanced waste treatment plant and a subsequent 2-year demonstration period. The first unit of this treatment was placed in service on October 14, 1969, at a total construction cost of $756,000. The demonstration operating period was completed October 1, 1971.

The facilities constructed included a single sludge biological denitrification process for nitrogen removal. This process was integral with the activated sludge plant and was required to handle the whole flow. Methanol addition was used to stimulate denitrification.

Following the activated sludge plant, a tertiary plant was built for removal of phosphorus and suspended solids. The capacity of this plant was 2 mgd and included a reactor-clarifier for lime, alum and polyelectrolyte addition, recarbonation in separate basins by combustion of natural gas and two anthracite-sand rapid gravity filters. Small chlorination basins were constructed to study disinfection and were followed by quarter million gallon study ponds to observe algae and fish growth.

In addition, pilot plants were built to study the removal of salt and residual organic matter to demonstrate that the Santee water supply could be supplemented with reclaimed water. Three granular activated carbon tanks were installed to handle 100,000 gpd, followed by a De-sal ion exchange unit to treat 50,000 gpd and an electrodialysis plant for 50,000 gpd. This work was partially supported by a contract for $186,251. from the Environmental Protection Agency. These facilities were intended to show that the system previously approved by regulatory authorities could be replaced by in-plant treatment which was independent of the unique geological features at Santee. A period of studies on these new facilities and the overall system was essential if new discharge permits were to be obtained. During the study period, the percolation beds would remain in operation to protect the public use of the lakes and there would be no connections to the drinking water system. The studies would emphasize, on a field scale, the practical aspects of process operations, effluent quality, reliability, costs, public health safety and algae growth.

APPROACH TO STUDY

The Santee County Water District applied to the Federal Government for a demonstration grant based on the need to replace its percolation beds. After the grant was obtained, the project was organized and operated to produce a practical demonstration of the application of advanced waste treatment by a small sanitary district. The District got into the program because of defined waste treatment needs. The District was not and could not turn itself into a research organization for this project, therefore the normal design and construction approach was followed by an attempt at routine operation by regular personnel. During the project, the District still had to continue to provide its normal waste treatment and recreational services to the public.

The first step was to engage a sanitary engineering consulting firm to design the plant. The design was developed in 1967 - 1968 based on information available at that time. Minor laboratory tests were conducted on the raw sewage and secondary effluent. Information from pilot plants and full scale plants at other locations was adapted to the design but no pilot plant investigations were made for the Santee design.

The plant was built by a Southern California contractor who specializes in treatment plant construction. The job was let by competitive bidding. The machinery was composed of standard catalog items, mostly from wastewater equipment manufacturers. The construction was inspected by the District's regular staff.

The District's approach to operating the plant was to use its regular sewage treatment plant operators, no special personnel experienced in water treatment or tertiary treatment were hired. The operators did not have experience with this equipment either in a pilot or full sized plant, nor was there any special schooling at another plant or by the manufacturers. The consulting engineer was not required to provide an operating manual. The tertiary plant was considered to be just another part of the whole plant, not singled out for special procedures or assignments. Of course some operators spent more time in tertiary than others and became more familiar with it.

The Project Engineer, Chemist and Assistants were engaged at the end of construction. They were responsible for evaluating the performance of the units. The Project Engineer consulted with plant personnel on operations and modifications to the plant and set goals for the operations. There was no direct operation or checking of daily operations by the Project Engineer. Log books were kept by the operators. Chemical tests were performed on a rigid weekly program.

STUDIES WHICH WERE MADE

The first construction phase to a nutrient removal design capacity of two million gallons per day was built. However, after the construction was completed and during the start-up, the mining of the sand and gravel from the percolation beds was permanently discontinued. This eliminated the immediate need for an advanced waste treatment system to supply water to the lakes. The secondary effluent in excess of the percolation capacity would be bypassed for a few years around the lakes after lagooning and chlorination.

Since the plant was built and it was possible that the District would have need of advanced treatment at some future date, it was decided to go forward with the demonstration studies. The biological nitrogen removal equipment was the first into operation. After a start-up period, testing indicated that additional construction was desirable in the denitrification and sedimentation basins. Only minor and inconclusive information was obtained during the few days of composite sampling because of operating conditions. This data is not included in this report.

After a conference in Washington, May, 1970, the Federal Government decided it preferred to pursue other methods of nitrogen removal over single sludge nitrification-denitrification. Therefore additional funds were not made available and that process was discontinued to conserve limited operating and study funds.

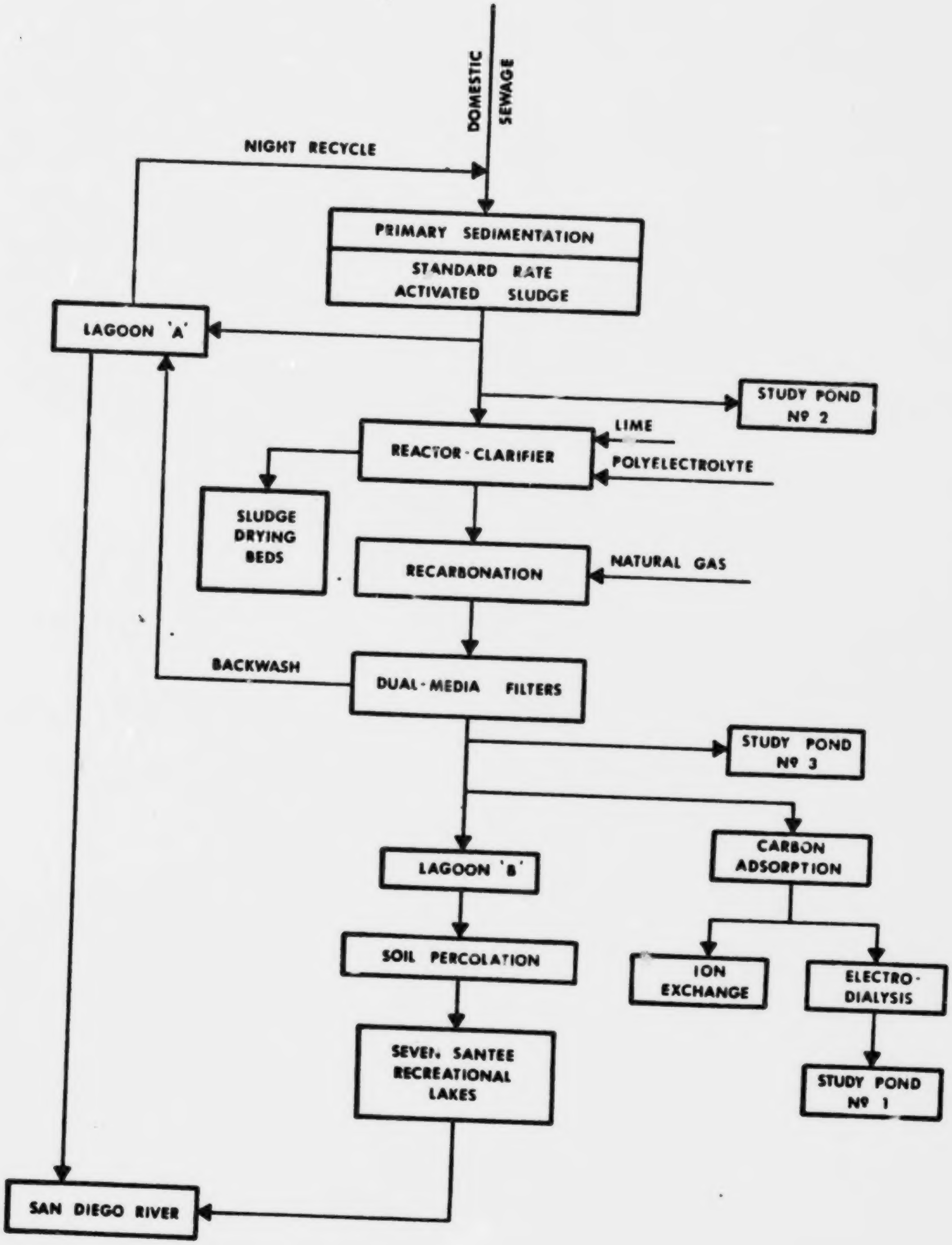
The reactor-clarifier, recarbonation and dual-media filtration were studied from May 25, 1970 to October 1, 1971. Most of this report is concerned with that work. The flow sheet of processes studies is shown in Figure 1.

Since the District had considerable difficulty in obtaining steady, high performing, reliable operation, and because many of the problems were felt to be of design origin, a second sanitary engineering consulting firm was engaged to review the tertiary plant. This review was conducted in the Spring of 1971 (3). The comments and recommendations of their review have been included in the discussion sections of this report where applicable.

An Assistant Project Engineer was hired in June, 1970, to direct the studies on carbon adsorption, ion exchange and electrodialysis. Those operations were completed on October 1, 1971, and the results are presented in separate reports (4, 5).

Two studies by outside agencies were planned to determine the acceptability of replacing the percolation beds with tertiary treatment plus chlorination. The first study was to estimate how serious the algae growth problem would be in the lakes without percolation. This study was conducted by the University of California, Irvine, and is included as Section VI of this report. They determined the absolute levels of algae growth under controlled laboratory conditions and made comparisons with field observations in special study ponds. In addition, growth limiting nutrients in the effluent were determined.

The second study was to have examined the removal of viruses by the tertiary plant and post-chlorination to show the lakes and swimming would still be safe for public use. This study was to have been conducted by the same personnel at the San Diego County Health Department that examined and certified the public health safety of the percolation beds. The study was not conducted, however, because the experimental period was short for public health studies in the opinion


DOMESTIC SEWAGE
NIGHT RECYCLE
PRIMARY SEDIMENTATION
STANDARD RATE ACTIVATED SLUDGE
LAGOON 'A'
STUDY POND Nº 2
LIME
POLYELECTROLYTE
REACTOR-CLARIFIER
SLUDGE DRYING BEDS
RECARBONATION
NATURAL GAS
BACKWASH
DUAL-MEDIA FILTERS
STUDY POND Nº 3
LAGOON 'B'
CARBON ADSORPTION
SOIL PERCOLATION
ION EXCHANGE
ELECTRO-DIALYSIS
SEVEN SANTEE RECREATIONAL LAKES
STUDY POND Nº 1
SAN DIEGO RIVER

of the Health Department, the non-replacement of the percolation beds by tertiary treatment eliminated the need for certification, and limited laboratory facilities at the Health Department.

LITERATURE

Several recent publications summarize the theoretical and experimental information which is available on lime treatment. These have all been published after the design and construction of the Santee plant and should be consulted for the most recent thinking on tertiary treatment. This Santee report will emphasize the operating experiences in 1970 and 1971 and not look back to the details of the concepts used in 1967 for the design.

The Environmental Protection Agency Process Design Manuals for Phosphorus Removal and Suspended Solids Removal (6, 7) provide a good starting point for reading on this subject. They review a wide selection of references and experimental data and discuss the important design features. Culp and Culp's book (8) on advanced waste treatment is also a good general reference. Seiden and Patel (9) present much plant and pilot plant data and a mathematical model for the process. Berg, Brunner, and Williams (10) reported on their studies of a pilot plant similar to the Santee plant. Stamberg's, et.al. (11) performed extensive jar tests which clearly show much of the phenomena involved in lime treatment. They examined relations between pH. lime dose, alkalinity, phosphorus, calcium and magnesium in various effluents. Haney and Hamann (12) discuss recarbonation with liquid carbon dioxide. Smith and McMichael (13) have developed cost information on tertiary treatment process.

ADDITION OF LIME

To meet the major objective of a high degree of phosphorus removal, the consulting engineers selected single stage lime treatment of secondary effluent in a tertiary plant. The various alternate processes and the situations where they are applicable are discussed in the above cited references. A brief review of the chemical equations applicable to the Santee plant is given below. This study was a demonstration of the use of tertiary treatment by a small sanitary district with emphasis on the operating and cost aspects. The study was not able to investigate the chemical theory of tertiary treatment.

Single stage treatment can be used where there is sufficient alkalinity and calcium in the water to produce the required floc at a moderate lime dose and pH. In a single stage treatment plant, sufficient lime slurry is added to reach the desired pH. The water remains at this pH a sufficient time for flocculation and sedimentation. The pH is then lowered to the final pH in a single adjustment. This pH is low enough to stabilize the water and prevent post-precipation of calcium carbonate. The water is then filtered and discharged.

The lime used was high purity calcium oxide and slaked to calcium hydroxide.

$$CaO + H_2O \longrightarrow Ca(OH)_2$$

The slaked lime is added to the reactor influent where it reacts with the alkalinity to form a calcium carbonate precipitate.

$$Ca(HCO_3)_2 + Ca(OH)_2 \longrightarrow 2\ CaCO_3 \downarrow + 2\ H_2O$$

There are two moles of calcium carbonate formed per mole of calcium hydroxide added. This is the basis for lime softening of water. The reaction is the main consumption of lime for the tertiary plant and largely determines the lime dose. The precipitate formed is a major portion of the sludge. Phosphorus is adsorbed to this precipitate. A high calcium carbonate content in the floc is believed to increase its settlability (6).

If there is not sufficient alkalinity and calcium in the water, another reaction with alkalinity will still occur.

$$NaHCO_3 + Ca(OH)_2 \longrightarrow CaCO_3 \downarrow + NaOH + H_2O$$

In this reaction only one mole of calcium carbonate is formed. Therefore the settlability of the floc could be different.

Another equation familiar from water treatment lime softening is the reaction of magnesium with hydroxide.

$$Mg^{++} + 2\ OH^- \longrightarrow Mg(OH)_2 \downarrow$$

This reaction is not important until the pH approaches 11. The gelatinous floc formed aides in clarifying the water, however, it also hinders sludge thickening and dewatering (6).

The concentration of phosphorus in the water is low and its consumption of lime in direct reactions is small. Phosphorus occurs in many forms in water and the reactions involved in its removal are complex and varied. If a secondary effluent is well treated, most of the phosphorus will be present as soluble orthophosphate. The reaction below is an example of the precipitation of phosphate as hydroxyapatite.

$$5\ Ca^{++} + 3\ HPO_4{}^{=} + 4OH^- \longrightarrow Ca_5OH(PO_4)_3 \downarrow + 3H_2O$$

Similar reactions occur with the other forms of orthophosphate, depending on the pH.

After the chemical reactions have taken place and the water has been settled, its pH is adjusted in a separate tank to stabilize the water.

The adjustment is made by reacting carbon dioxide with the excess lime to precipitate calcium carbonate.

$$Ca^{++} + CO_2 + 2OH^- \longrightarrow CaCO_3 \downarrow + H_2O$$

A heavy precipitation occurs in the pH 9-10 range which is the minimum solubility of calcium carbonate. If excess carbon dioxide is added to take the pH below the minimum solubility, soluble calcium bicarbonate will be formed and less sludge.

$$CaCO_3 + CO_2 + H_2O \longrightarrow Ca(HCO_3)_2$$

Therefore if say water of pH 7 is desired from a single stage recarbonation, the effluent water will contain more calcium hardness than would be obtained if the pH adjustment were made in two steps.

As can be seen from the above equations, the alkalinity, the calcium concentration in the secondary effluent, the degree of secondary treatment and therefore the forms of phosphorus, and the pH chosen for the reactor-clarifier and final effluent are significant factors in determining how well a lime tertiary process will perform.

SECTION III

PLANT DESCRIPTION AND OPERATION

The single stage tertiary lime treatment plant designed for Santee was based upon the information available in 1967-68. No pilot plant investigations were made at Santee. Plant visits, published reports and personal communications provided the background for the design. The basic selection of processes appears to be well suited to the Santee requirements and conditions. However, there was considerable operating difficulty with the detailed aspects of the design and equipment selection. Since there have been few published reports on this type of plant, these troublesome details will be commented upon when describing the equipment and operations. There have been plants built at other locations which have not had these problems.

LAYOUT

A site plan of the tertiary area is shown in Figure 2. The flow sheet of the system was given in Figure 1. Figure 3 is a photograph of the tertiary area. The reactor-clarifier is the large tank in the foreground, the control building is to the right and the filters are the two tanks in the back to the left. Figures 4 and 5 are closer views of the tertiary plant with the reactor-clarifier on the right and the filters on the left. The concrete tanks in the center are for recarbonation. Figure 6 is the top of the reactor-clarifier showing the arrangement of the launders.

The secondary effluent comes from a standard rate activated sludge plant located at the same site. The plant is about two years older than the tertiary plant and is conventionally operated at about one-half design flow. The sewage is entirely domestic, rarely containing storm water, from the community of Santee.

The design flow of the tertiary plant was a maximum of 2 mgd or 1400 gpm. Since the flow to the secondary plant is only slightly in excess of 2 mgd, the low night flows were supplemented by recycle pumping from a lagoon which received the excess secondary effluent during the day. The recycle pumping was back into the force main leading to the secondary plant but its quality was satisfactory to return directly to the tertiary plant. It was put through the secondary plant because nitrogen removal was planned. This recycle allows fuller use of tertiary capacity and a nearly steady flow which considerably improves and simplifies operation.

The flow is pumped from the wet well to the rapid mix box of the solids contact type reactor-clarifier. From the rapid mix box it passes through the contact zone, flocculation zone and sedimentation zone. Lime is added at the rapid mix box or at the contact zone. The poly-

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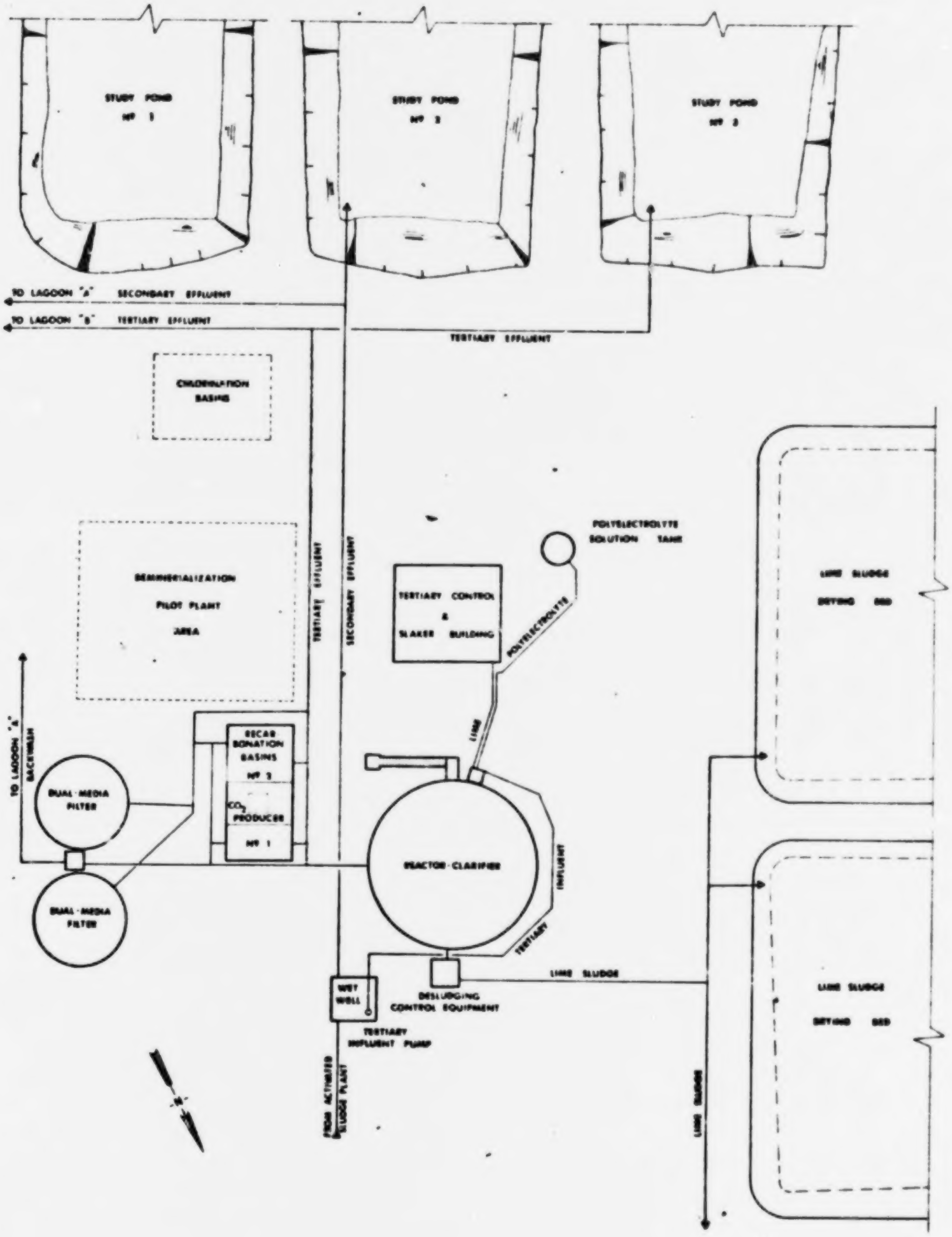


FIGURE 2 TERTIARY SITE PLAN

FIGURE 3. TERTIARY TREATMENT PLANT.

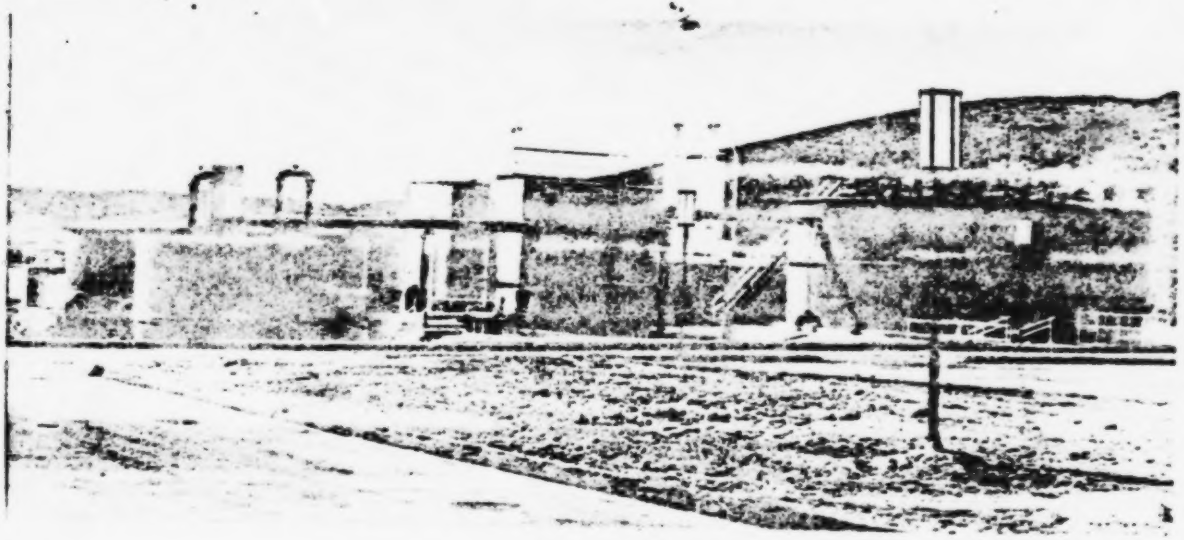


FIGURE 4. FILTERS ON THE LEFT AND REACTOR-CLARIFIER ON THE RIGHT.

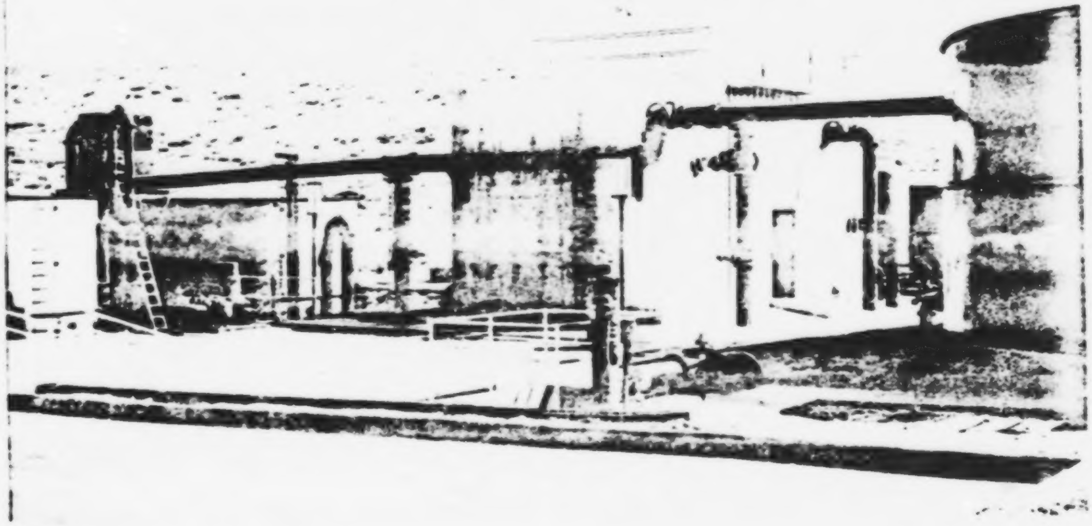


FIGURE 5. CONCRETE RECARBONATION BASINS WITH TERTIARY PUMP IN FOREGROUND.

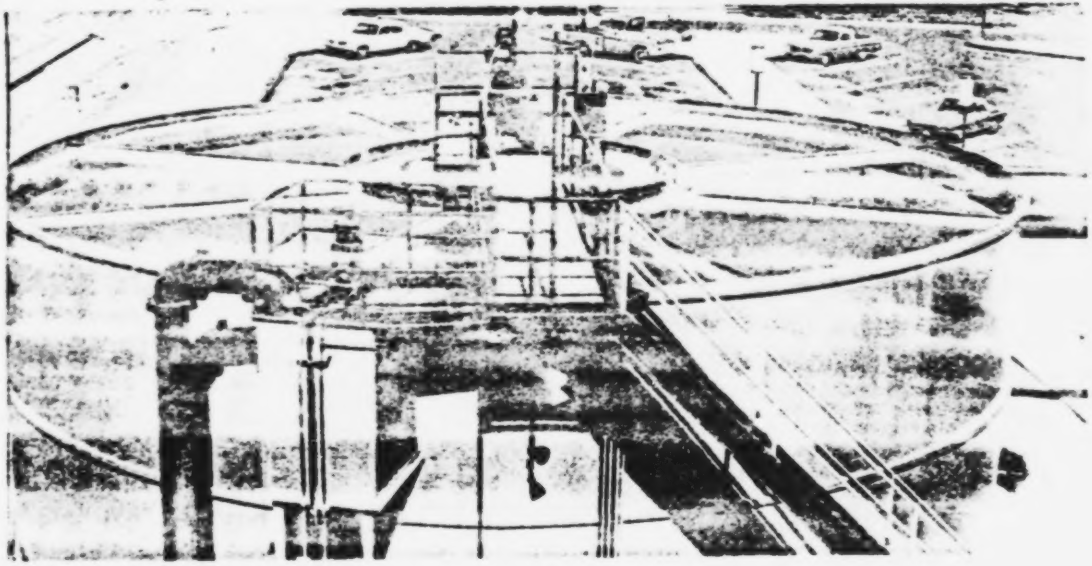


FIGURE 6. TOP OF REACTOR-CLARIFIER.

electrolyte is added in the contact zone. The sludge is removed by a rotary rake to a center well and then by gravity to sludge drying beds.

From the reactor-clarifier the flow goes to the recarbonation basins for pH adjustment. The piping arrangement around these basins is complicated so as to provide for various flow arrangements. The possibilities are (1) direct discharge from the reactor-clarifier, (2) pH adjustment and discharge, (3) filtration without pH adjustment, (4) partial pH adjustment to stability then filtration and discharge, (5) a second pH adjustment following the previous scheme so neutral water could be provided to the carbon adsorption, (6) pH adjustment in both basins to obtain maximum detention time before filtration, and (7) filtration directly after the reactor-clarifier followed by pH adjustment. These possibilities were set-up in 1967 to give maximum flexibility during the demonstration program. Flow patterns 1, 2, 4, and 6 were used at various times.

With this piping system there were excessive head losses through the basins which were not completely solved even though one major reconstruction was made. The water coming from the reactor-clarifier is unstable and will cause calcium carbonate deposits in the pipes which cannot be easily cleaned in the present arrangement. Hydraulic measurements indicated some pipes had a Hazen-Williams factor of less than 80. A more accessable piping system would have had less head problems and could be cleaned occasionally.

The flow to the filters is equally divided by a flow splitter box irregardless of the head requirements of each filter. When the head attains a certain set point, the filter is automatically backwashed by product water from the compartment above the filter. The backwash water goes to the secondary storage lagoon to be recycled at night. The tertiary effluent goes to a tertiary storage lagoon and then into the Santee recreational system. The flow for the study ponds was taken from these effluent pipes and the discharge from the study ponds went into the recycle lagoon.

EQUIPMENT

A single piece of equipment was provided for each function except filtration. There are a few days of lagoon storage for secondary effluent in the event of major breakdowns. The plant is not designed as a modulor of a larger plant or with provisions for duplicate equipment. All of the equipment must be taken out of service for maintenance and occasionally dewatered, therefore the plant cannot maintain continuous service. The plant's reliability is discussed in Section V.

Tertiary Influent Pump

The tertiary pump is a Layne and Bowler Company single stage, mixed flow, vertical drive, submerged impeller, Model 6 LM driven by a 15 horsepower motor. It is controlled by an Automatic Control Company class 1901 "reactospeed" variable resistor unit with an air bubbler level sensing unit. This equipment was to provide variable flows from 275 to 1400 gallons per minute on automatic operation or any given flow in that range on manual operation.

The head-discharge characteristics of this pump were not suitable for the application. The pump curve has a "saddle" in it which allows the pump to cycle rapidly between two discharges on either side of the saddle. This is very bad for sludge blanket and filter operations. The automatic controls could not be made to function properly with this pump and were eventually abandoned. Even on manual control the pump curve was so flat that it was not responsive to control changes. Also if the flow to the wet well should drop below the pumping rate for only a few minutes the pump would pump the well down, shut off and not restart.

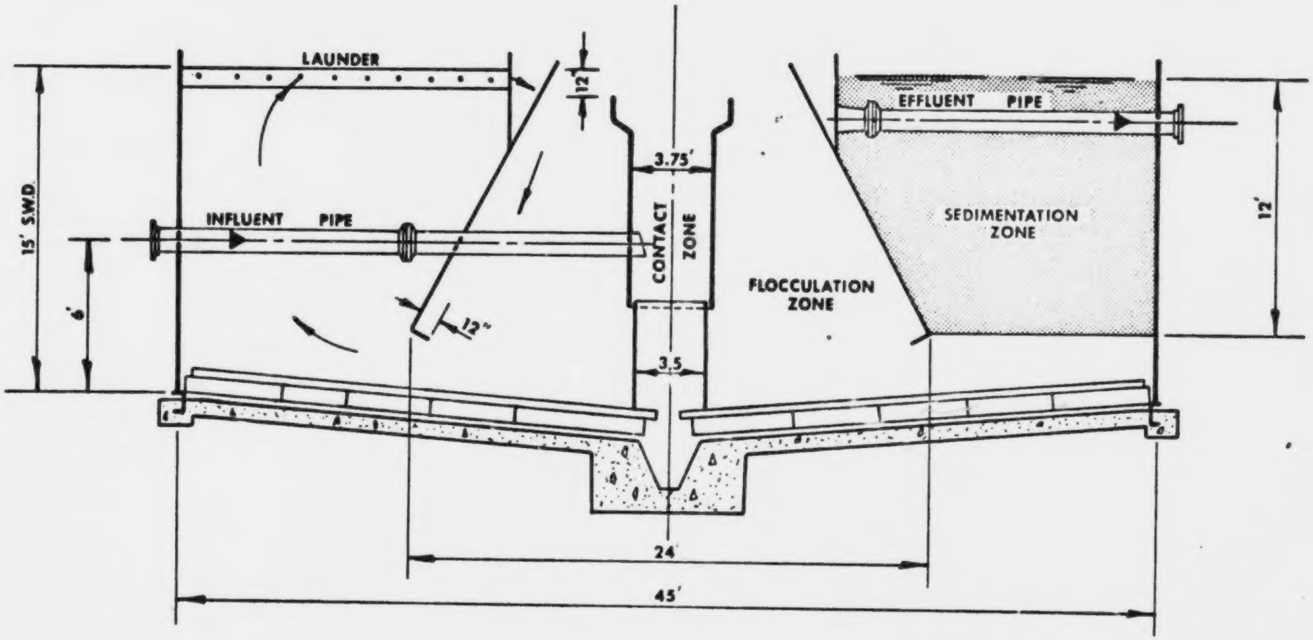
Reactor-Clarifier

This unit is a Rex-Reactor built by Rex Chainbelt Incorp., the principal dimensions and rates are shown on Figure 7 and the surface arrangement can be seen in the photograph, Figure 6. In general this unit gave good service but there are a number of small points to be made about the installation.

The rapid mix tank was not effective since too small a mixer was installed. For a time, lime was added in the inlet pipe to the rapid mix box to get some mixing in the pipe but this will cause scale in the pipe. The rapid mix box also had foam problems because of the free discharge from the influent line. This was worse when there were problems in the secondary plant. There will also be foam problems when the ejector which pumps lime to the rapid mix box sucks air from the slaker slurry well. A lime feed line also went directly to the contact zone of the reactor-clarifier but this line was under water and could not be kept clean. It should have gone up the side and over the top of the reactor-clarifier so that it could have been replaced without dewatering the tank.

A turbine is mounted at the top of the contact zone to draw sludge up and into contact with the influent and fresh lime. This turbine operates from three to sixteen rpm, and is manually adjusted. External sludge recirculation was not provided. It does not appear to be essential but it would be desirable especially in variable flow situations where frequent adjustments must be made.

It was observed that there was more turbidity near the outer perimeter of the sedimentation zone than in the center or the middle of the zone. Corks were placed in the discharge holes of the outer four



Volume Sedimentation Zone :
118,800 gal.

Sedimentation Zone Area:
1418 ft^2

At 2 m.g.d.
Sedimentation Loading .98 g.p.m./ft^2
Sedimentation Retention Time:
86 min.

FIGURE 7 REACTOR-CLARIFIER DIMENSIONS

feet of the launders. It is questioned whether the flange at the bottom of the cone is large enough to protect the sedimentation zone from disturbance. It was also possible on some days to observe the movement of the twin armed sludge sweep by a cloud of turbidity even though it was kept at minimum speed.

Desludging was by gravity to the sludge beds, regulated by an automatic valve controlled by a timer. A pump was included in the system for flushing the lines automatically at the end of each desludging cycle with clarifier effluent water. The 1½ to 2" lines provided were too small, 4" would have been better since only a small amount of scaling would plug them up. Also there should have been connections so that the sludge line under the reactor-clarifier could be backflushed at high pressure. The valve cylinders, solenoids, and pump all had to be replaced from corrosion and required frequent servicing.

Lime Feeder and Slaker

The lime is delivered pneumatically to an overhead storage bin. From there it is fed by a Wallace and Tiernan Model G-109 EF gravimetric feeder to a Wallace and Tiernan plug mill type series A-758 slaker. There should be a way to measure the amount of lime in storage without climbing to the top of the bin and removing a plate. The water tightness of this cover plate is soon lost. On a few occasions, there were metal or glass objects in the lime which stuck in the feeder gate causing excessive deliveries of lime. Perhaps a removable coarse screen could be placed in the system. The slaker was operated satisfactorily on the plant's pressurized secondary effluent water system. It was later switched to the potable water system because of breakdowns in the effluent water supply.

Originally two small centrifugal pumps were installed in parallel to pump lime to the reactor-clarifier. They were connected with small diameter, rigid piping with sharp angles and no clean-outs. The pumps continually leaked lime because an adequate packing material could not be found and their shafts scored. The piping frequently plugged up and had to be disassembled to be cleaned. After some months of struggling with this system. it was replaced by a single ejector with quick change couplings. Water was drawn from the top of the clarifier to a Peerless pump Model Pe-Sl x2 x8-70 which discharged through a 1¼ inch bronze Penberthy Series 160A ejector. The ejector was connected directly to the slaker and all the rigid piping was replaced by flexible hose. The constant level tank was also eliminated. An extra ejector and hose set were kept ready for quick replacement. This system stopped the leakage and was much cleaner. Perhaps the feed water for the ejector pump should have been filter effluent instead of clarifier effluent since the small particles in the clarifier effluent apparently wore the pump seals rapidly.

Polyelectrolyte

The newer polyelectrolytes are of high molecular weights and can be made up in only very dilute solutions. In installing polyelectrolyte facilities, a stock solution tank large enough to hold two to three days supply of 0.1% solution was used. The polyelectrolyte manufacturer's (Nalco Chemical Co., Chicago) set-up instructions were followed closely and no difficulties were encountered. Only one solution tank was used, the feed was stopped for about one hour while the solution was being dissolved. An eductor funnel, connected to the water supply through a water meter, is essential. The tank was mixed by compressed air from a grid at the bottom of the tank. A metering chemical feed pump, manually adjusted, pumped to a diffuser in the contact zone of the reactor-clarifier. The solution was diluted ten to twenty times before discharge.

Sludge Beds

The lime sludge drying beds are approximately 100 feet by 100 feet and about four feet deep. An overflow box with adjustable weir boards was located in the opposite corner from the inlet. This box is adjusted to take a clear decant from the surface although if the sludge was not settling well there could be short circuiting and some sludge going out the overflow line. The overflow line was connected to the secondary effluent pond. There was an earth ramp in each bed for cleaning equipment access. The beds were a reasonable size for cleaning with a front-end loading tractor. There was no measuring equipment to determine the volume of sludge.

Instruments and Sampling

A remote reading propeller meter was located in the tertiary influent line. This meter was calibrated by pumping into a partially emptied reactor-clarifier. The meter was read in the tertiary control building but not the main plant control room.

A closed loop pH control system was designed for the reactor-clarifier. A probe was located near the top of the flocculation zone, the transmitter was attached to the railing, and the receiver, recorder, and lime feeder controller were located in the control house. This equipment was to determine the pH of the reaction continuously and periodically adjust the lime feed. However, there is a long lag time between the change in dosage and the new pH. With the equipment provided, a constant value of pH could not be obtained, there was always at least some cycling. A variation of one pH unit over a day was expected. The probes were not reliable and the meter was hard to standardize and this led to abandonment of the equipment and operation by dosage. The probe seemed to lose accuracy within hours after adjustment and scaling was severe. The probe was easily damaged during cleaning and the manufacturer was not able to stop leaks into the probe box which corroded the connections.

The only alarms were for overheating of electric motors. An attempt was made to build a more elaborate alarm system because of the frequent short shutdowns, but this was never functional. Useful alarm functions would have been for no flow, no lime, no CO_2, limits on pH, and excessive turbidity. Other useful instruments would have been a remote reading blanket finder and a continuous turbidity meter on the filter effluent.

There was no automatic pH control equipment for the recarbonation. A single probe and a recording pH meter were installed. After observing the pH, the operator manually adjusted the CO_2 producer.

The lime feeder is controlled by a continuous reading balance. The lime quantity was determined by the set point on the scale and the totalizer reading.

New sampling facilities were constructed for the study program. Composite samples were taken of the influent and effluent of the reactor-clarifier and dual media filters. Since the flow was steady, the sampler did not have to proportion according to the flow. A chemical metering pump was hooked up to send a continuous sample to a solenoid which periodically diverted some of the flow to a refrigerated sample bottle. The solenoid was controlled by a two clock timer, one for frequency and one for duration. The solenoids were mounted at the refrigerator so the sample was stored immediately.

Recarbonation

The recarbonation unit is a Walker Process "Carball" size 1, with a capacity of 1,680 pounds of CO_2 per day. The furnace burns natural gas. It was installed between two concrete basins which contain diffusion equipment. A controlled gas flow could only be added to one basin at a time so the first basin with a diffuser depth of 11 feet was always used.

Culp and Culp (8) state that CO_2 is quickly dissolved in water so an 8 foot diffusion depth is enough. They say, however, that the time for the dissolved CO_2, hydroxide and carbonate to react takes up to 15 minutes in cold water. The first basin was 8 feet wide and 16 feet long with over and under baffles for mixing. The retension time with a 1.5 mgd flow is 11 minutes plus some time in pipes and filter chamber, therefore there seems to be adequate time before filtration to stabilize the water. The second basin was 14 feet wide and 16 feet long.

The recarbonation step was a major problem area, it frequently disrupted testing programs and distracted the staff from the study a large amount of time. There were furnace problems and basin problems.

The furnace problems were caused by improper specifications and installation resulting in overheating the unit which would shut down automatically and then restart, usually on a fifteen to thirty minute cycle. This passed slugs of untreated water through recarbonation basins. There were two problems. The first was too small a compressor drive motor which overheated and eventually burned out. The second was using secondary effluent water for cooling. In the summer this is too warm and expensive potable water had to be substituted. The frequent on-off operation led to deterioration of the unit, the heater tubes cracked flooding the furnace, also the fire eye was replaced.

The basins accumulated considerable sludge which took several days to remove after dewatering the basins. This was only done occasionally, probably much of the sludge was washed through the basins onto the filters. Other projects on the basins included adding foam sprays in the diffuser area, a lot of foam can be produced when the secondary plant is not operating well. Also the diffuser pattern was changed and walkways and a ladder were built to give working access to the basins.

The experience at Santee with a combustion unit for producing CO_2 was not good. It appears that liquid CO_2 vaporized from bulk storage at the plant would have been preferable (12). Such equipment should give a wider operating range, the CO_2 producer does not seem very flexible. The throttling valve on the vaporized gas might also be controlled automatically by a closed loop from the pH meter. The head loss problems caused by pumping a lot of air into the basin from the CO_2 producer would be eliminated. Also it would be a much quieter installation. In a small plant a little higher cost for purchasing CO_2 would more than be offset by the labor saved.

Dual Media Filters

Two Eimco SVG-M gravity filters of 22 foot diameter were installed, Figure 8. Each filter has a filtered water storage compartment above the filter compartment. This water is used for gravity backwashing. The flow enters from a splitter box, passes down through the media and underdrain system and up through the storage compartment and out the product line. The media is 12 inches of anthracite (0.85 to 0.9 mm effective size, width not to exceed three times thickness) over 12 inches of sand (0.4 to 0.5 mm effective size, 1.65 uniformity coefficient). They are equipped with an air-water wash. The air supply is 1150 cubic feet per minute at 3 psi for a rate of 3 cfm/ft^2. The filters could be set to backwash automatically at a specified head. The time of air-water wash and the rate of backwash were variable. The amount of backwash water is limited to the capacity of the storage compartment.

The filtered water storage compartment should be covered because a

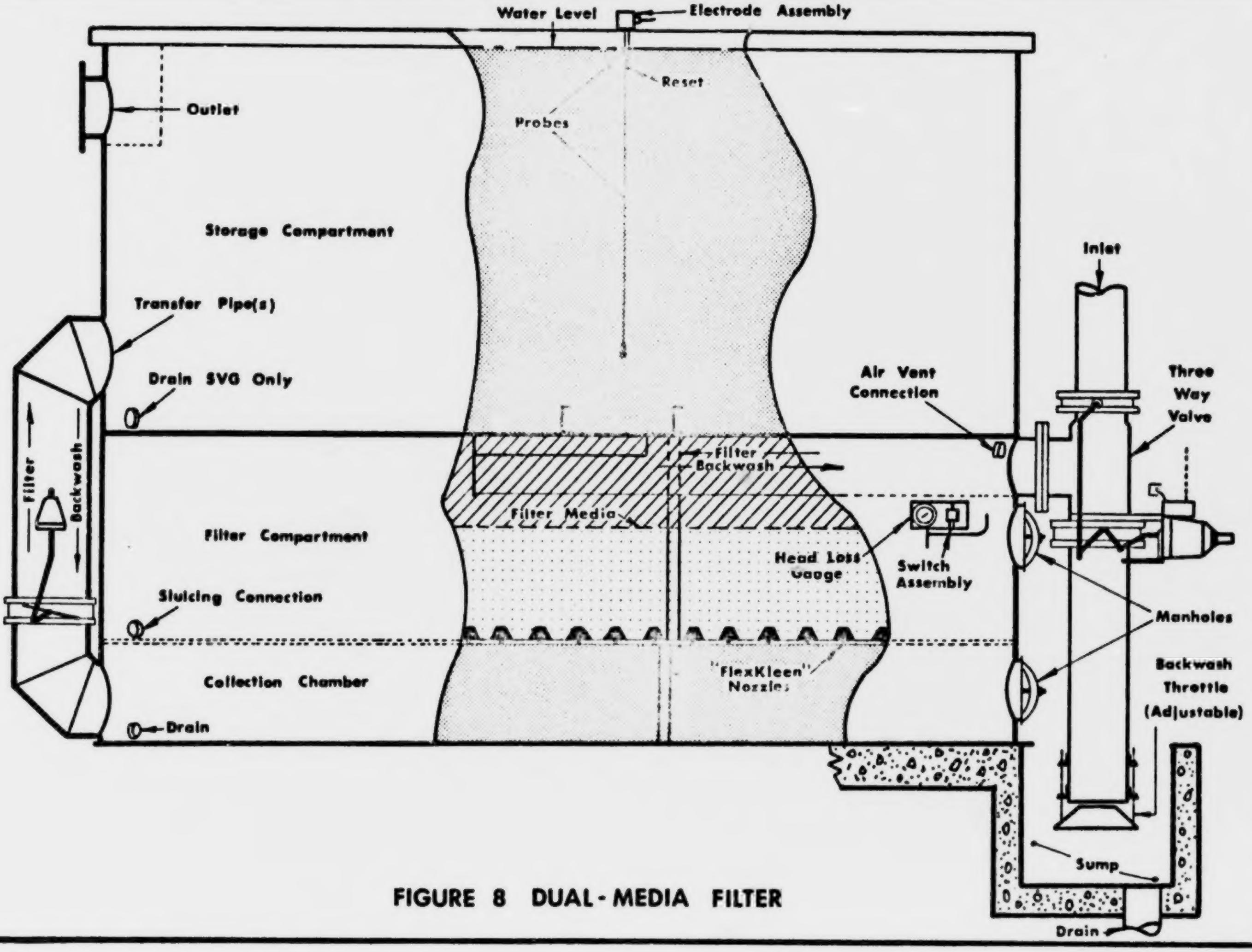


FIGURE 8 DUAL - MEDIA FILTER

heavy growth of filamentous algae attached itself to the walls and sloughed off into the effluent. Also several dead ducks were found in the compartment. The underwater light and window were not practical because of algae growth on the window. With this layout the expansion of the filter bed during backwash cannot be observed because of the storage compartment. The mounting of the control panels on the side of one tank was not good. The filter effluent line was subject to air binding which caused the filter to overflow and the flood caused severe damage to the panels. Air is easily entrained in the filter effluent pipe because there is a free fall from the storage compartment weir to the ground inside the pipe.

COAGULANTS

The lime used is called "Shastawite" chemical granule quicklime. It was purchased from Charles Pfizer and Co., Lucerne Valley, California, and trucked to Santee in about 25 ton loads. The composition is 96.5 to 98.0 percent calcium oxide (CaO), 0.6 to 1.2 percent magnesium oxide (MgO), 1.0 to 1.5 percent silica (SiO_2) and 0.5 to 1.0 percent alumina (Al_2O_3). It has a shaken bulk density of 72 lbs/cu ft and a loose density of 65 lbs/cu ft. On a Tyler screen there is a trace on +5 and 98 percent on +100.

The polyelectrolyte selected for plant use was Nalcolyte 676 from the Nalco Chemical Co., Chicago. It is a water soluble anionic polymer with a molecular weight greater than three million and a viscosity of 5000 centipoise in a 0.5 percent solution.

Nalco 676 was selected after jar testing their line of polymers on Santee effluent. The District chemist also did some tests on Dow A-23 and Calgon ST 270. They also appeared usable.

OPERATIONAL PROCEDURES

At the end of the study period the various procedures used by the operators were reviewed with them. Their comments and experiences with the reactor-clarifier are summarized below.

Flow Rate. The performance of the reactor-clarifier is very dependent upon flow rate. Flow rates from 500 to 1400 gpm were used. Not much difference is observed between 500 and 700, above 700 gpm (0.5 gpm/ft^2) control problems start. Steadiness of flow is important, especially at higher flow rates. When starting the pump, the flow should be turned up gradually. Say 100 gallons per minute every 30 minutes. Also the turbine speed should be greatly increased to lift the blanket some.

Control Observations and Tests. The first thing the operator does is examine the sludge from the sampling valves located on the side of the tank at various depths. He looks for density and location of the sludge blanket. He tries to maintain the blanket above the six foot from the bottom sampling valve. If it had dropped below that valve, the turbine speed is increased. The next observation is from the top of the tank. He looks at the clarifier compartment to see if the fines of the blanket are staring to break loose and come up. Then the turbine speed will be readjusted. The color does not seem important, it appears to be influenced more by the quality of the secondary effluent than by reactor-clarifier operation. Light green was observed when the algae bloomed in the secondary lagoon. An early afternoon grab sample is taken for orthophosphate removal and turbidity from the clarifier effluent. This allows the effect of the adjustment in the morning to be observed. Also this is the peak flow in the biological plant and therefore the worst effluent. Sludge samples are taken from the sampling valves and tested for total solids concentration. The solids concentration also was estimated quickly by observing the volume after centrifuging.

Operation by Controlling Dosage. There was considerable difficulty in maintaining automatic pH control equipment, and it would show errors of more than one pH unit. So after it was abandoned the pH was controlled for several months by a grab sample measurement of pH every two hours and manual correction of the slaker. The range of pH variation was about .4 units with this control system. Of course twenty-four hour staff is essential. That method was replaced with control of the reactor-clarifier by feeding a set lime dosage rate. With some experience the correct dosage in parts per million is determined, then adjustments only have to be made for different flow rates. Since the plant is run with a constant flow, this method gives no more variation in pH than the manual pH control method and needs considerable less attention. It is planned to continue permanently with dosage control. It was not possible to detect any difference in the three places in which to add lime, the influent pipe, rapid mix box or directly to the contact zone. Therefore operating problems and clogged pipes will determine the application point.

Turbidity in the Clear Zone. Some solids come up along the outside edge of the tank, especially when the flow rate is being changed. This appears due to velocity changes at the bottom edge of the cone. The outer five or six holes of the launders can be plugged to decrease the amount of floc in the effluent. It doesn't appear that this overloads the other launder holes. Isolated clouds of turbidity are also seen in the sedimentation tank. Sometimes this appears to be caused by the rake. The rake appears to part the blanket causing a hole that water shoots up through carrying a cloud of turbidity up into the sedimentation tank. The lowest rate speed was used. Surface scum resulting from reactions within the reactor does not seem to be a problem. Some surface scum carries over the wall from the rapid mix box. It is due to foaming from the ejector pumping of lime and from free discharge of secondary effluent.

Blanket. The clarifier has been operated at sludge concentrations from zero to about seven percent. A blanket appears to much improve the performance of the equipment. Without the blanket, the phosphorus removal is poor and there is no control of the floc which is formed. It appears that at least three percent solids blanket is necessary. Carrying too dense or too deep a sludge blanket causes the blanket to lose fines. However, when the blanket becomes too thin, it loses its cohesion and has large discharges of solids. The rate of change of flow is very influential. There didn't seem to be any problems with the sludge blanket going anaerobic.

Polyelectrolyte. The polyelectrolyte seems to improve the management of the sludge blanket if the dosage is correct. Operations were begun with a feed of .4 mg/l which apparently was too much and the blanket did not pull together and perform well. The effluent was cloudy, whitish in appearance. There were fines coming from the blanket but they did not look like the fines which come out when the flow is too great. When the dosage was reduced to .2 mg/l the performance was greatly improved over that of the larger dosage and also over that of no polyelectrolyte. Performance also seems good with .1 mg/l. The use of the polyelectrolyte seems to increase the strength of the blanket and allow flow variations without large discharges of solids. Therefore, polyelectrolyte is a definite advantage and its use is recommended. The polyelectrolyte feed was adjusted manually. Short term changes in dosage didn't seem too important.

SECTION IV

PLANT PERFORMANCE

The general objective of the tertiary plant was phosphorus removal and the operations were directed towards this. Suspended solids removal was of less concern at Santee because it is likely that there will always be a large storage lagoon for flow regulation following the tertiary plant. The disinfection, if the percolation beds were removed, would be carried out in the one mile pipeline from the lagoon to the lakes.

A surveilance program, for a demonstration of the tertiary treatment plant's performance was maintained from the first addition of lime on December 9, 1969, to September 30th, 1971. Periodic chemical tests were conducted by the District's chemists and log books were kept by the operators. That information will be used to make an evaluation of the tertiary plant's performance. The operating period is broken up into four sections where specific objectives were followed. The performance of the filters was not as good as expected so during the last six weeks, the regular program was discontinued and emphasis was placed on observing the filters.

For convenience in making records and handling data during a long study period, the day of the year rather than the date was used in identifying study periods and samples. For example, February 10 would be listed as Day 41.

LABORATORY METHODS

Samples were composited over a twenty-four hour period, at an interval of about thirty minutes. The flow was steady, so the samples are also proportional to the flow. They were refrigerated while being taken. Four locations were used, the influent and effluent to the reactor-clarifier and influent and effluent to the dual media filters. The samples were collected twice a week, about 7:30 in the morning and laboratory work was started immediately. The testing program is given in Table 1, only three tests were done once per week. Some grab testing was done for spot checking after the composite program was completed. The locations and dates of the samples are shown on the data sheets in Appendix B.

The 1965 Standard Methods (10) was followed in the procedures for total phosphorus, orthophosphate, nitrate, nitrite, calcium, magnesium, total hardness, BOD, turbidity, alkalinity, suspended solids, volatile suspended solids, total solids, conductivity, color, and methylene blue active substances. The FWPCA Manual (11) was used for COD, total kjehldahl and ammonia. Filtrate was prepared with glass fiber filters. Conductivity is corrected to 25° centigrade. Initially the District used the stannous chloride method for total phosphorus without the

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TABLE 1 LABORATORY PROGRAM FOR COMPOSITE TESTS

Reactor-Clarifier Influent (Secondary Effluent)	Reactor-Clarifier Effluent	Dual-Media Filters Influent	Dual-Media Filters Effluent
Total Phosphorus	Total Phosphorus		Total Phosphorus
Ortho-Phosphate Filtrate	Ortho-Phosphate Filtrate	Ortho-Phosphate Filtrate	Ortho-Phosphate Filtrate
Total Kjeldahl			Total Kjeldahl
Ammonia Filtrate			Ammonia Filtrate
Nitrite Filtrate			Nitrite Filtrate
Nitrate Filtrate			Nitrate Filtrate
pH	pH	pH	pH
Alkalinity	Alkalinity	Alkalinity	Alkalinity
Total Hardness	Total Hardness	Total Hardness	Total Hardness
Calcium Filtrate	Calcium Filtrate	Calcium Filtrate	Calcium Filtrate
Magnesium Filtrate	Magnesium Filtrate	Magnesium Filtrate	Magnesium Filtrate
Turbidity	Turbidity	Turbidity	Turbidity
Suspended Solids	Suspended Solids	Suspended Solids	Suspended Solids
Volatile Suspended Solids			
COD	COD		COD
COD Filtrate	COD Filtrate		COD Filtrate
BOD*	BOD*		BOD*
Color*	Color*		Color*
Conductivity	Conductivity		
Methylene Blue Active Substances			Methylene Blue Active Substances

* once per week

addition of acid. After Day 99, 1971 the stannous chloride method was used with the addition of acid.

The pH and alkalinity of water will change toward equilibrium with storage. There was concern on how to obtain this data. At night the sewage is diluted with recycled water from the secondary effluent lagoon. During parts of the study, the hourly and daily fluctuations in lime dose and reactor-clarifier pH were considerable and irregular. The CO_2 producer was often cycling on and off. Therefore obtaining a representative grab sample or knowing the degree of error would have been difficult. Since the laboratory was not receptive to frequent grab samples during the day and none were possible at night, the alkalinity and pH measured on the composite samples are reported. The magnitude of variation in pH upon storage for twenty-four hours was checked on four days. The results are shown in Table 2. The value in Table 2 is as if the whole sample were held for twenty-four hours rather than collected over twenty-four hours and analyzed immediately. The reported pH's for the reactor-clarifier effluent might be a few tenths to one-half pH unit lower than if grab samples were averaged for that day. The difference will be greatest at the higher lime dosages.

TIME SCHEDULE OF OPERATIONS

There were two periods of data taking. The first period was from May 25 (Day 145) to August 28 (Day 240), 1970 and the second period was from November 12 (Day 316), 1970, to September 30 (Day 273), 1971. Start-up was prior to the first period and regular log records and chemical analyses are not available. In the period from 240 to 316, 1970, the plant was shut down or operating irregularly while a major relocation was made in connecting pipes between units. Also many small changes and additions were made resulting from the operating experience already obtained. The tertiary study project was terminated on Day 273, 1971.

During period one, the hydraulic head problem limited the flow to one mgd and the lime dose was not accurate because of large leakage from the packings of the slurry pumps. The objective of the operations was to try for smooth running while waiting for the reconstruction to begin. During period two, flows varied from one to two mgd and an accurate lime dose could be determined because the slurry pumps were replaced by an ejector.

The flow pattern until Day 78, 1971, was from the reactor-clarifier through the first recarbonation basin where the CO_2 was added, through the second recarbonation basin where no CO_2 was added and then to the dual media filters. That was to give maximum retention time after carbonation and before filtration. It was also hoped that some sludge would settle in the basins, especially when control of the blanket was occasionally lost and it discharged into the reactor-clarifier effluent. On Day 78, the second recarbonation basin was eliminated from

TABLE 2 ALKALINITY AND pH CHANGES WITH STORAGE.

Sample Location	Date	Time	pH	Alkalinity mg/l as $CaCO_3$
Reactor-Clarifier Effluent	91, 1971	7:30	9.7	252.9
	"	11:30	9.4	244.9
	"	15:00	9.5	248.9
	92	7:30	9.4	249.0
Dual-Media Filter Influent	91, 1971	7:30	7.9	243.6
	"	11:30	7.9	239.6
	"	15:00	8.0	241.0
	92	7:30	8.1	245.5
Reactor-Clarifier Effluent	97, 1971	7:30	9.8	170.4
	"	11:30	9.8	160.8
	"	15:00	9.8	160.8
	98	7:30	9.6	153.6
Dual-Media Filter Influent	97, 1971	7:30	7.4	158.4
	"	11:30	7.4	158.4
	"	15:00	7.5	159.6
	98	7:30	7.5	163.2
Reactor-Clarifier Effluent	194, 1971	7.30	11.0	328.2
	"	11:30	11.0	328.2
	"	15:30	10.9	326.6
	195	7:30	10.9	328.2
Dual-Media Filter Influent	194, 1971	7:30	8.5	218.2
	"	11:30	8.0	160.8
	"	15:30	7.7	154.3
	195	7:30	7.6	147.7
Reactor-Clarifier Effluent	215, 1971	7:30	10.4	188.0
	"	11:30	10.3	181.5
	"	15:00	10.4	183.1
	216	7:30	10.3	179.9
Dual-Media Filter Influent	215, 1971	7:30	8.1	178.2
	"	11:30	8.0	174.9
	"	15:00	7.8	173.3
	216	7:30	7.4	166.8

the flow stream. For the remainder of the study, only the first recarbonation basin was used. This eliminated some head losses and made more operating head available to the filters. Also the desludging equipment problems on the reactor-clarifier had been solved and operating procedures had improved.

Various combinations of lime dosage and flow were tried by the operators during period one and the early part of period two to gain experience with various equipment loadings. During the latter half of the study program more narrow ranges of lime dosage were maintained for extended periods. Beginning on Day 60, 1971, the operators were asked to try to keep the pH between 9.5 and 10.0. This is one suggested mode of operation for the single stage process where there is sufficient alkalinity to operate in this pH range. From Day 146, 1971, until the end of the study, the operators were requested to operate from a pH of 10.5 to 11.0. It was also requested that the pH be adjusted in the recarbonation basins to 8.0 to 8.5 in the period Day 60 to 146 and to a pH of 8.5 to 9.0 from Days 146 to 273.

The addition of polyelectrolyte was begun on Day 116, 1971, at a concentration of 0.4 mg/l. On Day 162 this was reduced to 0.2 mg/l, on Day 214 it was further reduced to 0.1 mg/l and on Day 257 it was raised back to 0.2 mg/l for the remaining study time.

During period one, the tertiary pump and the slaker were operated on manual and the filters on automatic backwash. During period two, automatic control of the pump was tried from Day 316 to 358, 1970, and from 33 to 40, 1971. It was not satisfactory due to the characteristics of the pump and was not further used. Even on manual, the control and output of the pump continued to deteriorate. After Day 145, 1971, only flows in the range of one mgd were used. Automatic closed loop control of pH in the reactor-clarifier was tried irregularly from Day 316, 1970, to 12, 1971, and from 103 to 105, 1971. It was not satisfactory because of problems with the probe, difficulties in standardizing and the response characteristics of the controller. From Day 12 to Day 154, 1971, the reactor-clarifier was controlled by the operators taking a grab sample, usually a few times per shift, and then adjusting the slaker. From Day 154 to 273, 1971, a dosage control system was used, with spot checking of grab pH samples. The ejector for pumping lime to the reactor-clarifier was put into permanent service on Day 322, 1970. Automatic initiation of filter backwashing was operated from Day 316, 1970, to 105, 1971. By that time the controls could not be further repaired and new control boxes were not received in time to be used in the study. Since the flows were in the one mgd range, only one filter was used after Day 207, 1971.

REACTOR-CLARIFIER

The average tertiary flow and lime dose for each week is given in

Table 3. These rates are calculated using the operating time from the tertiary pump time clock and therefore are the flow and lime dose when the plant was running during the week. They are plotted at the mid-point of the week in Figures 9 and 10. During the first data period from Day 145 to Day 240, 1970, there was continual lime spillage due to pump problems. This spillage was estimated at 20%. Therefore the dose reported in this period is perhaps 20% higher than actually was received by the unit. The daily flow and lime dose were also calculated using a 24-hour day and are reported in Appendix A.

Two days per week the laboratory carried out a program of chemical analyses on composite samples. The lab program is given in Table 1 and the results in Appendix B. There are some additional results on dual-media filter effluent for other days because that water was analyzed also as the influent for the demineralization pilot plants. There were also periods of time when the filters were by-passed because of continual recarbonation problems. The last composite analysis was made on Day 225, 1971 (August 13). The emphasis was then shifted to studying the filters and the reactor-clarifier was only monitored by some grab tests performed each weekday. These results are given in Appendix Table B-5.

Only two samples per week make it difficult to follow the effects of operating procedures on performance. There were often large daily fluctuations in flow and lime dose (Appendix A). Therefore the data evaluation is split up into a number of phases where various general objectives were pursued. The data is averaged over the phase. These phases are as follows. The first study period Day 145 to 240, 1970, where a constant flow was maintained and various hydraulic and equipment problems were investigated in preparation for reconstruction. Day 316, 1970, to Day 59, 1971, where a variety of flows and dosages were tried. Day 60 to Day 145, 1971, where it was attempted to maintain the pH between 9.5 and 10 and use as high a flow as possible. Day 146 to Day 225 where the pH was to be maintained between 10.5 and 11 and the flow decreased to about 1 mgd. The chemical data are averaged for these periods and reported in Table 4.

The average removal of phosphorus in the reactor-clarifier was satisfactory. A lime dosage of 60 mg/l removes 85% to a residual of 1.74 mg/l as P. A lime dosage of 200 mg/l removes 95% to a residual of .77 mg/l. The residual phosphorus versus pH is shown in Figure 11.

The removal of soluble orthophosphate in the reactor-clarifier was also satisfactory. The 60 mg/l dosage removed 92% to a residual of .85 mg/l as P. The 200 mg/l dosage removed 97% to a residual of .34 mg/l. The soluble orthophosphate residual versus pH is shown in Figure 12.

The average sedimentation zone loading rate in the reactor-clarifier for the period of 60 mg/l dosage was .84 gpm/ft^2. For the 200 mg/l

TABLE 3 AVERAGE WEEKLY FLOW AND LIME DOSE

Day	Tertiary Pump Operating Hours	Flow M.G.D.	Lime Dose mg/1
1970			
145-152	149.6	1.01	188
152-159	159.2	.96	230
159-166	158.9	.96	191
166-173	160.7	1.03	267
173-180	161.3	.99	253
180-187	159.8	1.00	182
187-194	163.2	1.01	227
194-201	165.2	.99	199
201-208	163.4	.98	189
208-215	149.3	1.02	106
215-222	167.0	.99	125
222-229	167.4	.99	121
229-236	162.1	1.01	138
236-240	96.0	1.00	115
316-320	88.6	1.28	230
320-327	163.7	1.42	270
327-334	168.9	1.74	165
334-341	165.9	1.86	145
341-348	168.0	1.88	143
348-355	167.9	1.90	213
355-4	312.3	1.58	175
1971			
4-11	165.8	1.13	214
11-18	162.8	.88	136
18-27	214.8	1.57	125
27-32	75.5	1.62	---
32-39	155.6	1.84	131
39-47	187.8	1.78	124
47-53	144.3	1.12	157
53-60	167.5	1.34	120
60.67	163.8	1.81	77
67-74	164.2	1.78	71
74-81	166.4	1.89	70
81-88	160.4	1.96	58
88-95	165.9	1.66	52
95-102	161.9	1.49	43
102-109	167.2	1.70	50
109-116	91.5	1.72	51
116-123	164.9	1.69	62

TABLE 3 AVERAGE WEEKLY FLOW AND LIME DOSE (continued)

Day	Tertiary Pump Operating Hours	Flow M.G.D.	Lime Dose mg/l
1971			
123-130	167.0	1.58	50
130-144	335.2	1.59	60
144-152	184.4	.90	108
152-158	141.7	.90	149
158-165	167.3	.82	203
165-172	165.6	1.12	178
172-179	165.4	1.12	217
179-187	189.4	1.27	192
187-193	137.2	1.22	242
193-200	165.4	1.17	183
200-208	26.4	.94	---
208-214	143.6	1.05	---
214-221	164.0	1.04	197
221-229	190.6	1.11	164
229-235	143.5	1.07	188
235-242	162.4	1.06	204
242-251	212.0	.98	225
251-256	119.5	.94	203
256-263	147.3	1.12	251
263-270	144.4	.80	269
270.273	71.1	1.12	216

dosage period it was .51 gpm/ft^2.

The daily flows versus the suspended solids in the reactor-clarifier effluent are plotted in Figures 13 and 14. The first figure is for lime only from the beginning of the study to Day 115, 1971 and the second figure is for operation with polyelectrolyte from Day 116 to the end of the study. Nalco 676 was used with a dosage range of .1 to .4 mg/l. The best dosage was .2 mg/l. The polyelectrolyte improved the control of the reactor-clarifier and decreased the number of days with high solids discharge. But it did not improve the water clarity on the best days. A flow of 1 mgd is a clarifier rate of about .5 gpm/ft^2 and a flow of 2 mgd is about 1 gpm/ft^2. It is not apparent from the data that the lower flow rates improved effluent quality but the operators felt they had much better control of the situation and the plant was more stable with minor flow variations. The consulting engineer who reviewed the plant design (3) recommended a maximum flow rate of .75 gpm/ft^2 or a capacity of 1.5 mgd. The project staff concurs in that loading recommendation for Santee circumstances.

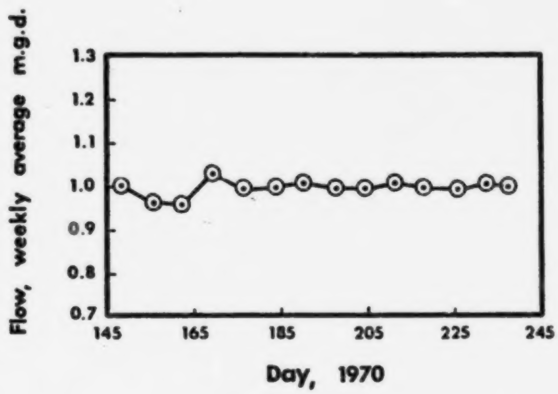

FIGURE 9. FLOW, PERIOD ONE

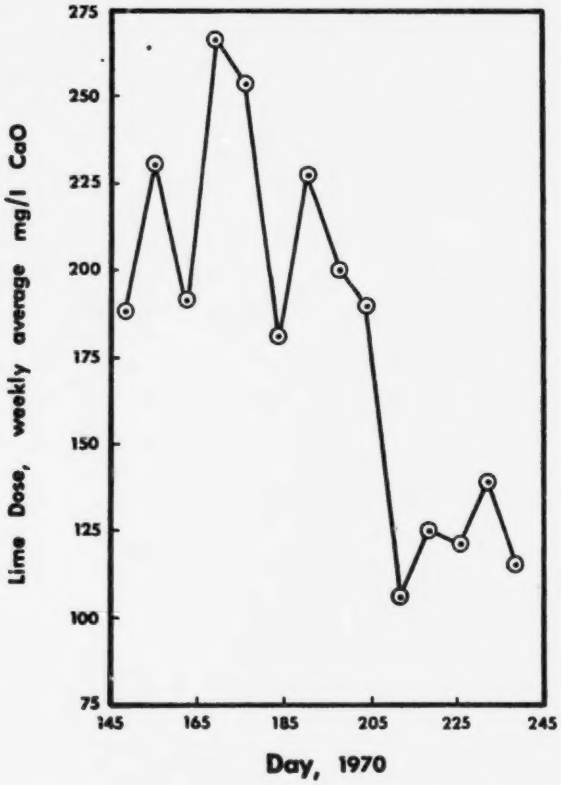

FIGURE 10. LIME DOSE, PERIOD ONE

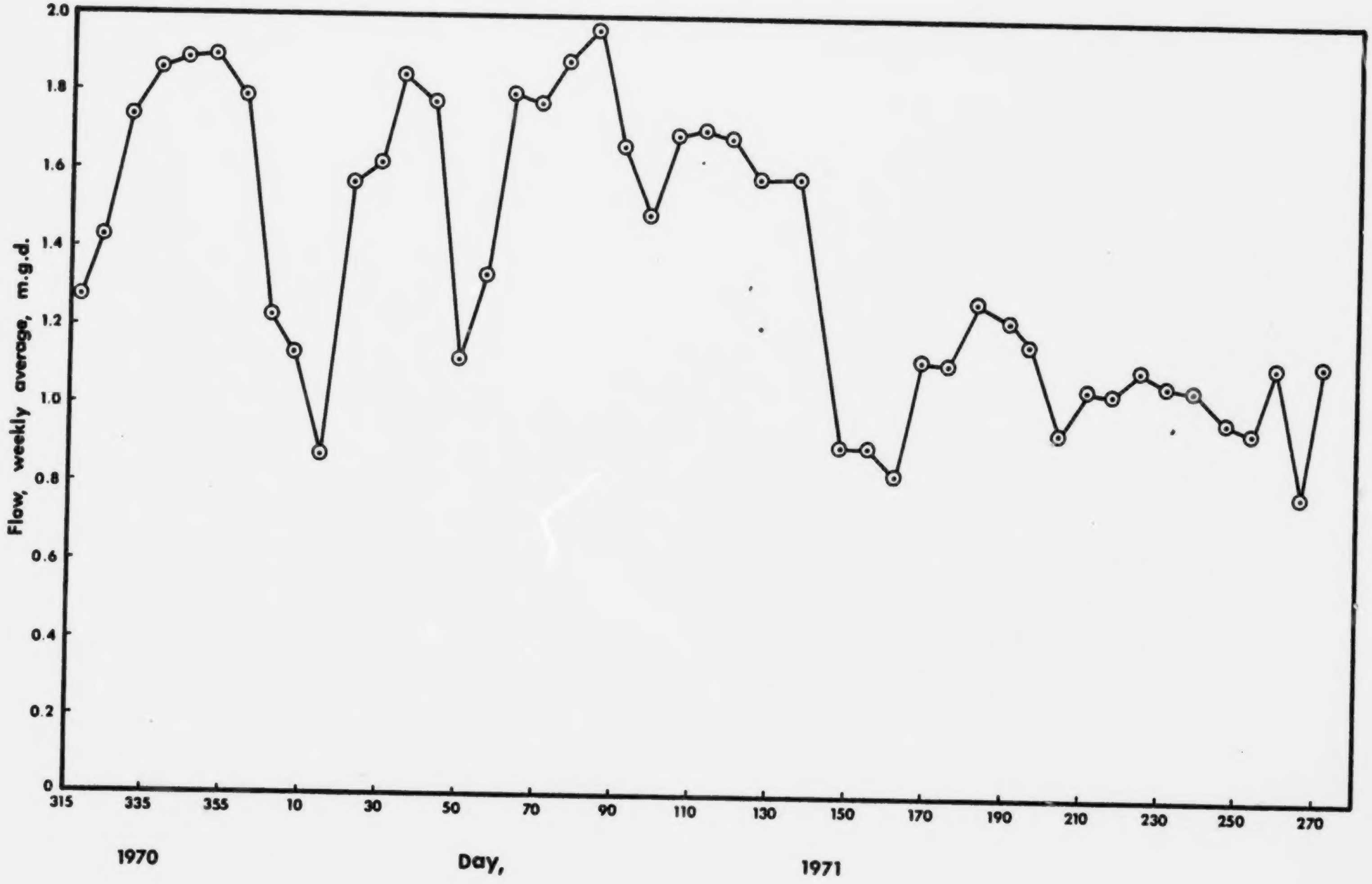

FIGURE 9. (Continued) FLOW, PERIOD TWO

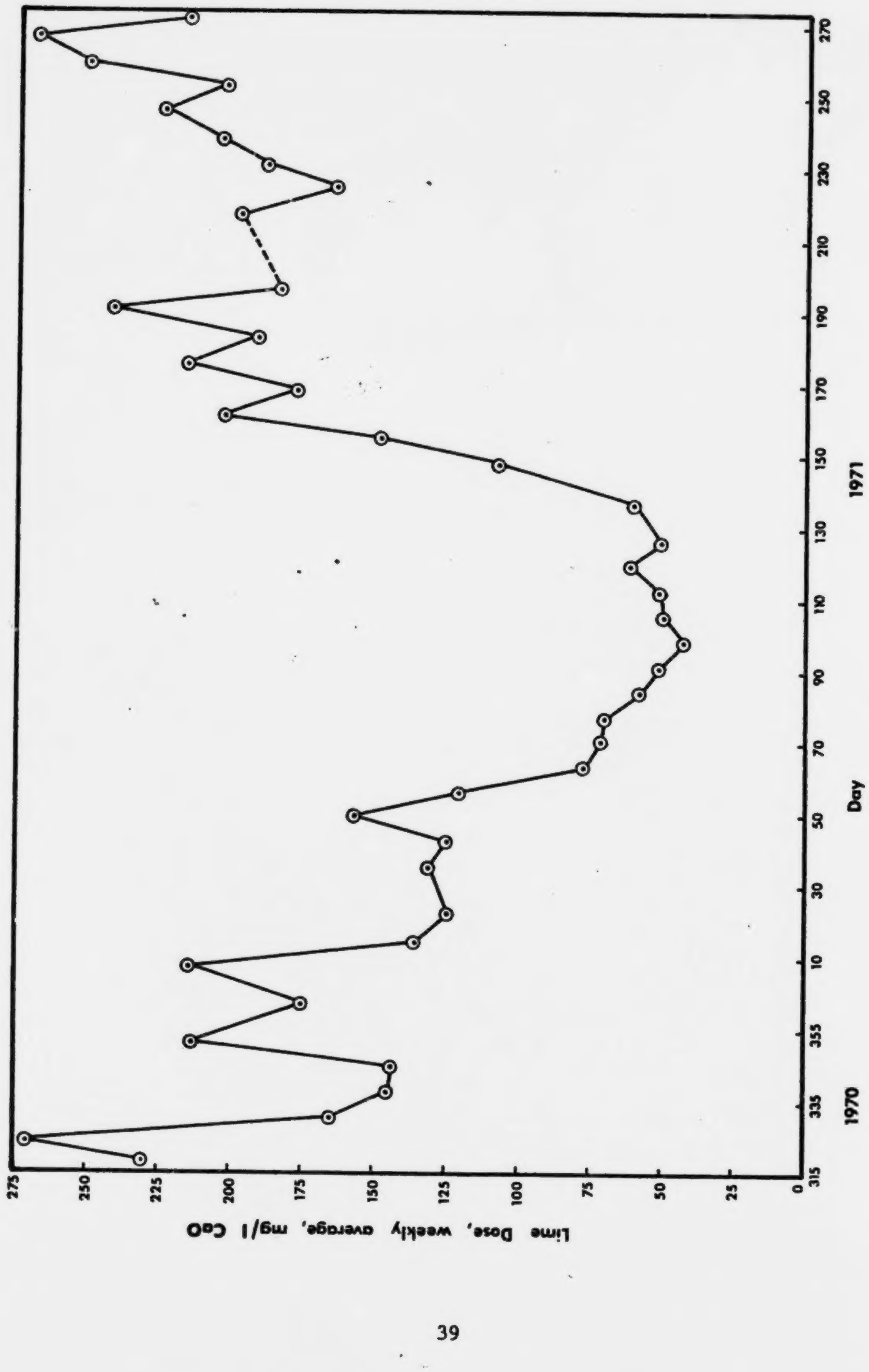

FIGURE 10. (Continued) LIME DOSE, PERIOD TWO

TABLE 4 AVERAGE CHEMICAL RESULTS.

Parameter	Location	Day 145-240 1970	Day 316-59 1970-71	Day 60-145 1971	Day 146-225 1971
Flow M.G.D.	---	1.00	1.52	1.72	1.04
Lime Dose mg/1	---	181	168	58	199
Total Phosphorus mg/1 as P	R-C inf	16.5	13.9	11.4	14.9
	R-C eff	.49	1.89	1.74	.77
	D-MF eff	.87	1.08	1.85	.72
Percent Removed	R-C inf to eff	97.03	86.40	84.74	94.83
Percent Removed	R-C inf to D-MF eff	94.73	92.23	83.77	95.17
Ortho Phosphate filtrate mg/1 as P	R-C inf	14.0	12.3	10.4	12.1
	R-C eff	.25	.83	.85	.34
	D-MF inf.	.73	.98	1.69	.77
	D-MF eff	.62	.73	1.74	.50
Percent Removed	R-C inf to R-C eff	98.21	93.25	91.83	97.19
Percent Removed	R-C inf to D-MF eff	95.57	94.06	83.27	95.87
pH composite sample	R-C inf	7.1	7.4	7.3	7.4
	R-C eff	10.2	10.2	9.6	10.6
	D-MF inf	7.2	8.5	8.0	8.4
	D-MF eff	7.3	8.4	8.0	8.2
Alkalinity composite sample mg/1 as $CaCO_3$	R-C inf	166	231	145	169
	R-C eff	143	217	134	71
	D-MF inf	123	235	198	126
	D-MF eff	138	220	190	137

Location: R-C reactor-clarifier
D-MF dual media filter
inf influent
eff effluent

TABLE 4 AVERAGE CHEMICAL RESULTS (CONTINUED).

Parameter	Location	Day 145-240 1970	Day 316-59 1970-71	Day 60-145 1971	Day 146-225 1971
Hardness mg/l as $CaCO_3$	R-C inf	386	406	415	396
	R-C eff	321	353	414	365
	D-MF inf	316	367	439	356
	D-MF eff	354	370	439	349
Calcium Filtrate mg/l as Ca	R-C inf	83	94	95	91
	R-C eff	98	102	109	129
	D-MF inf	96	104	118	122
	D-MF eff	116	106	117	121
Magnesium Filtrate mg/l as Mg	R-C inf	43.7	41.5	43.2	41.0
	R-C eff	19.1	25.2	34.7	10.2
	D-MF inf	18.6	26.0	34.9	12.8
	D-MF eff	21.3	25.6	35.6	11.4
Suspended Solids mg/l	R-C inf	64	54	43	58
	R-C eff	35	119	60	52
	D-MF inf	23	42	20	80
	D-MF eff	15	34	23	30
Turbidity units	R-C inf	7.2	8.1	8.5	12.2
	R-C eff	6.3	26.1	18.7	9.4
	D-MF inf	1.2	8.6	3.7	14.3
	D-MF eff	1.2	4.0	2.7	2.9
COD mg/l	R-C inf	63.8	69.2	57.3	49.4
	R-C eff	---	45.2	38.5	26.5
	D-MF eff	31.5	38.2	30.9	23.3

TABLE 4 AVERAGE CHEMICAL RESULTS (CONTINUED).

Parameter	Location	Day 145-240 1970	Day 316-59 1970-71	Day 60-145 1971	Day 146-225 1971
COD Filtrate mg/1	R-C inf R-C eff	50.2 ---	51.6 38.5	42.3 33.7	36.2 24.8
Kjeldahl Nitrogen mg/1 as N	R-C inf D-MF eff	8.02 5.19	15.61 12.95	9.43 6.03	7.81 6.25
Ammonia Filtrate mg/1 as N	R-C inf D-MF eff	2.69 2.52	9.92 8.35	3.76 2.06	3.19 3.28
Nitrite Filtrate mg/1 as N	R-C inf D-MF eff	1.42 .26	2.06 .32	1.22 .23	.51 .31
Nitrate Filtrate mg/1 as N	R-C inf D-MF eff	6.20 4.73	.74 .69	1.71 1.54	1.06 1.17
Volatile Sus. Solids	R-C inf	---	27	30	35
BOD mg/1	R-C inf R-C eff D-MF eff	--- --- ---	36 2.4 10.1	25 5.4 7.5	23 1.4 6.3
Color units	R-C inf R-C eff D-MF eff	39 --- ---	38 24 26	35 26 30	34 16 18
Methylene Blue Active substances	R-C inf D-MF eff	--- ---	.51 .80	.16 .13	.15 .19

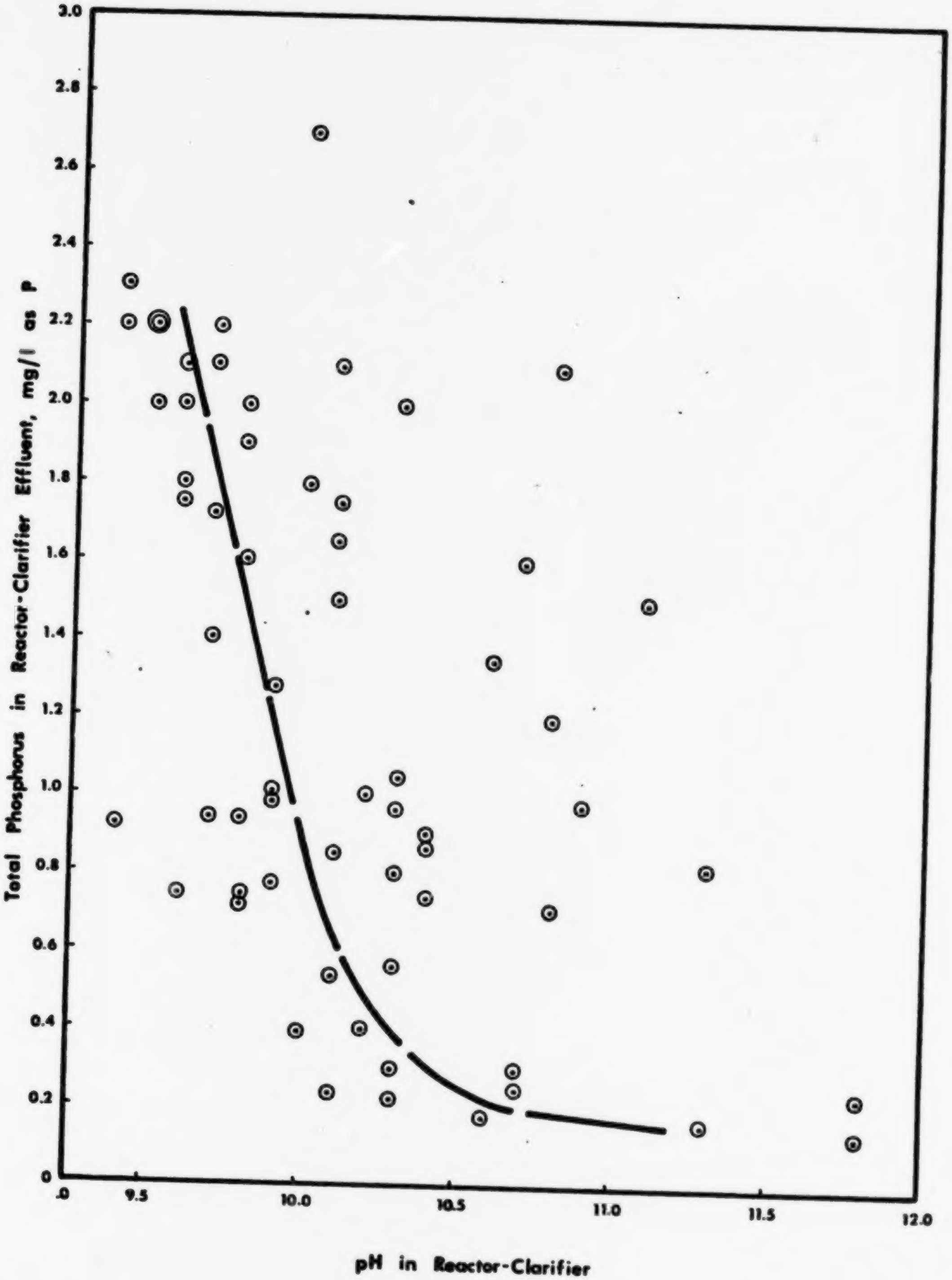

FIGURE 11. TOTAL PHOSPHORUS vs. pH IN REACTOR-CLARIFIER

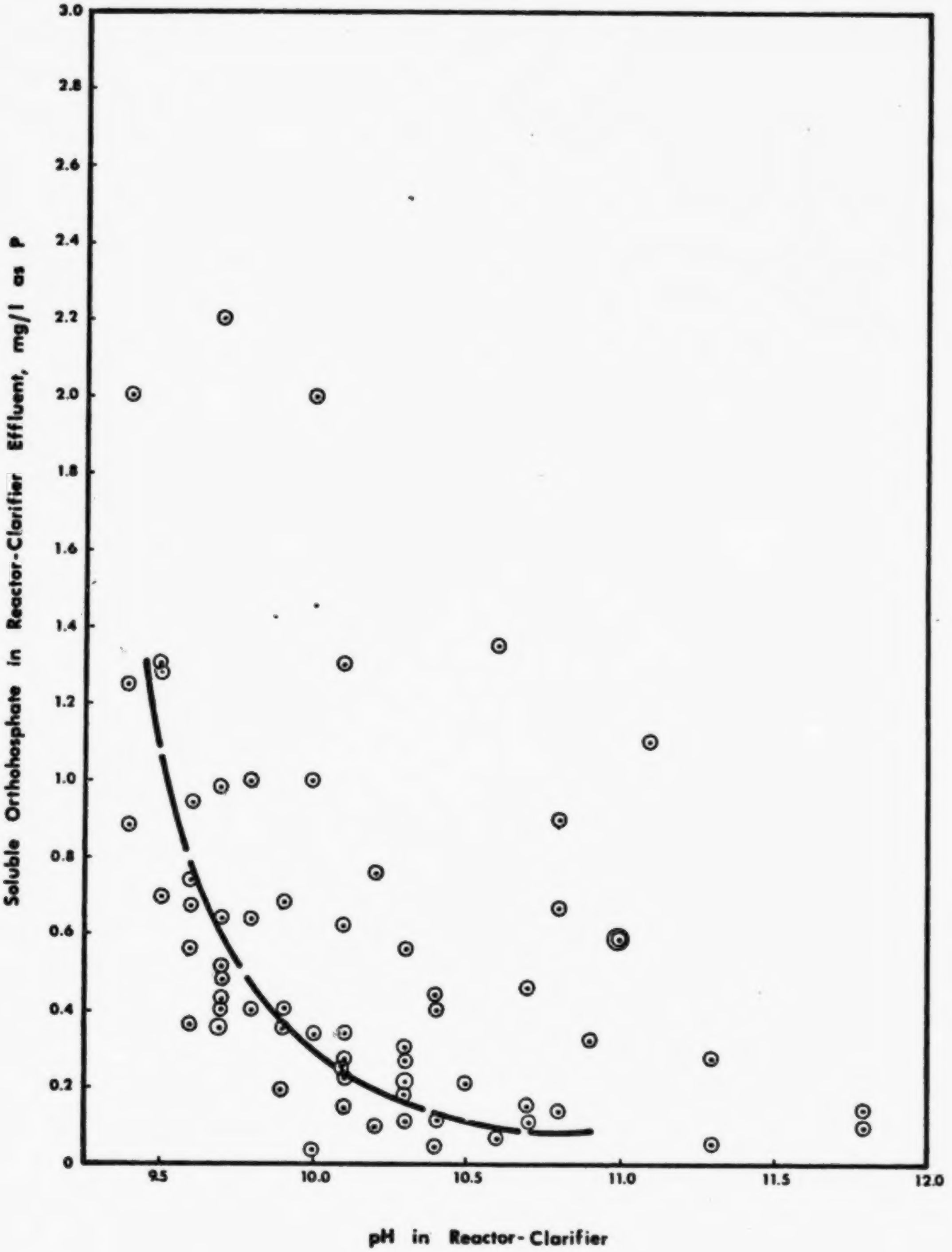

FIGURE 12. ORTHOPHOSPHATE vs. pH IN REACTOR-CLARIFIER

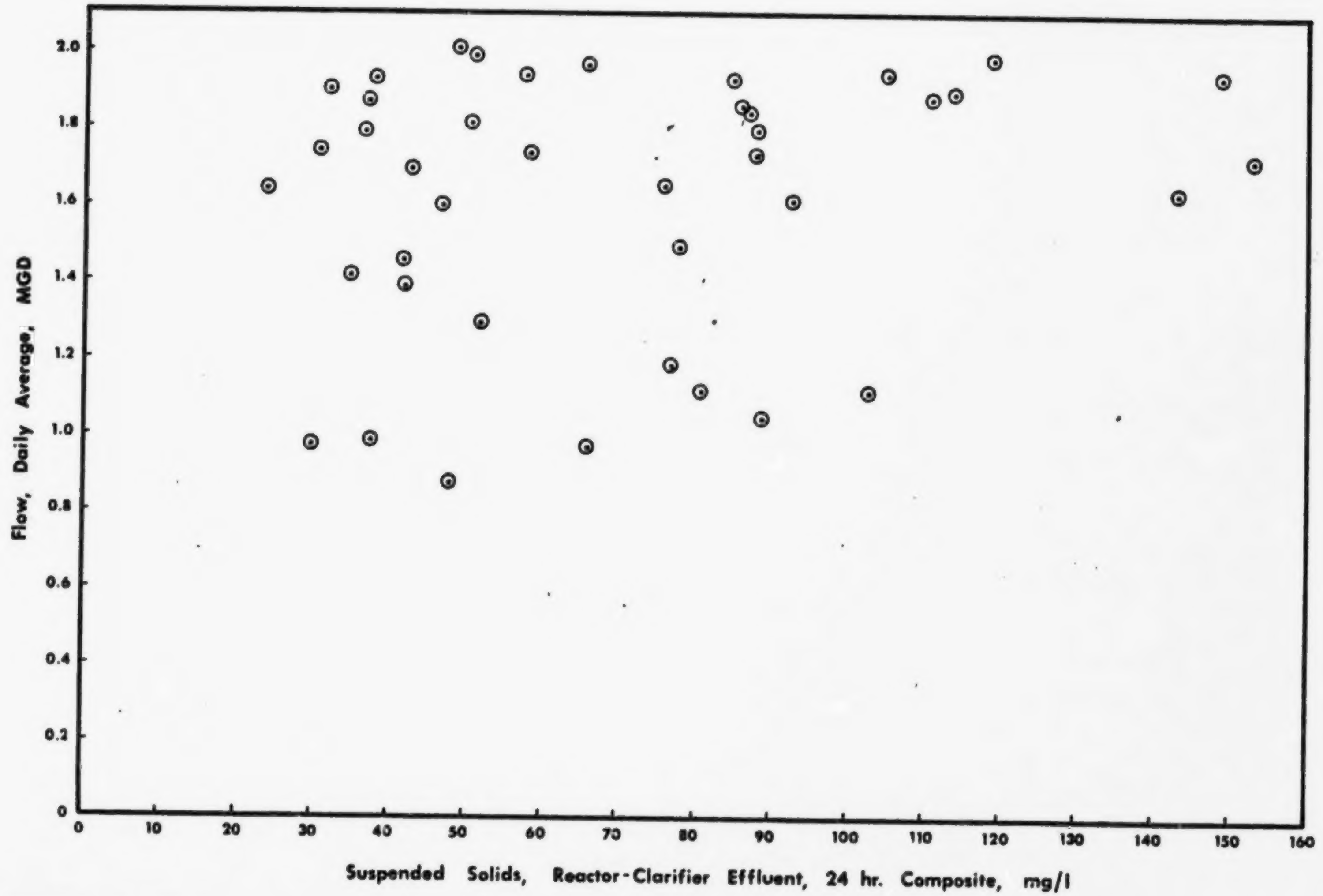

FIGURE 13. FLOW vs. SUSPENDED SOLIDS IN REACTOR-CLARIFIER, LIME ONLY

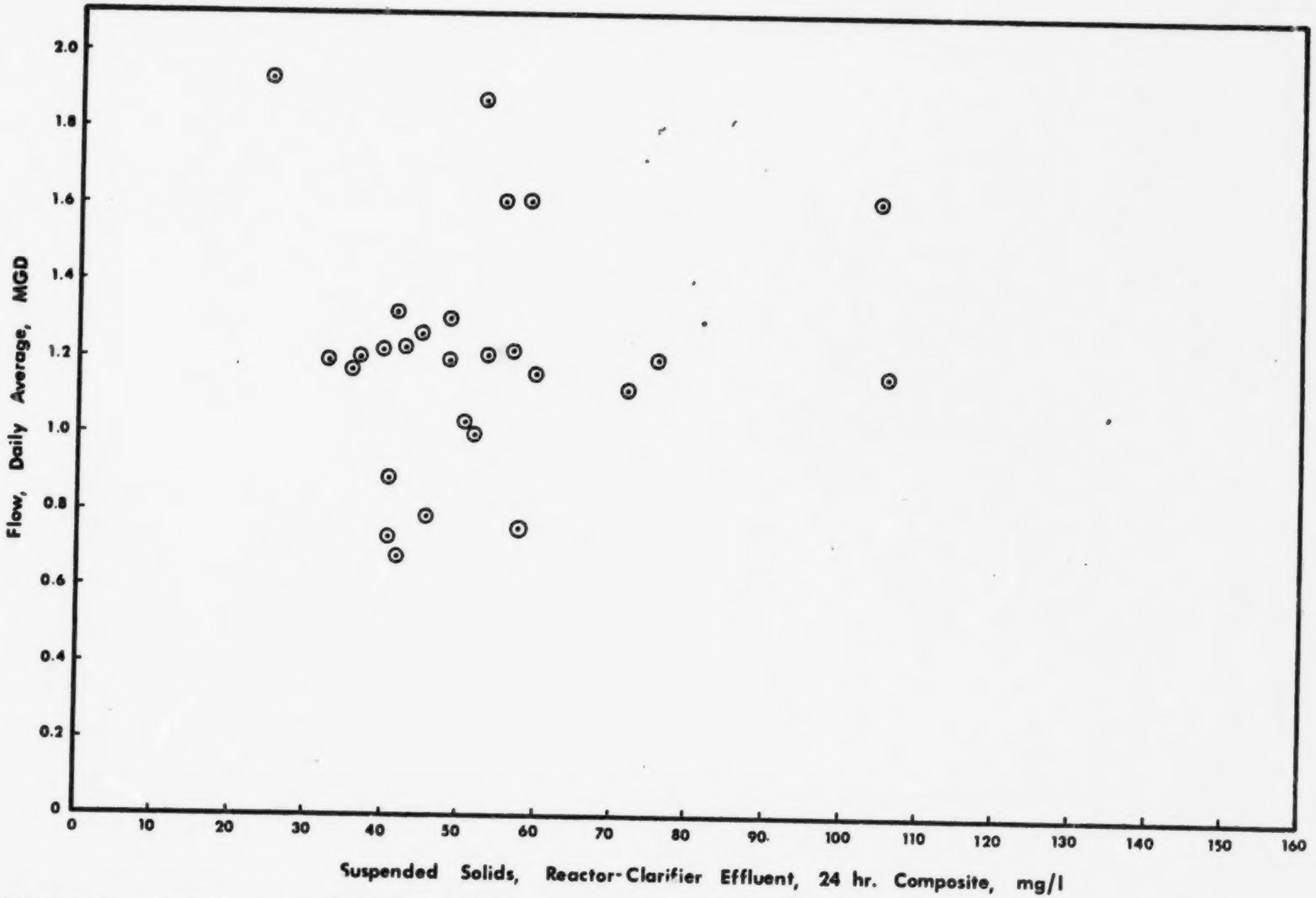

FIGURE 14. FLOW vs. SUSPENDED SOLIDS IN REACTOR-CLARIFIER, WITH POLYELECTROLYTE ADDITION

Dosage control rather than pH control of the reactor-clarifier was found to be more practical at Santee. The daily variations in alkalinity were not large enough to prevent use of dosage control. Figure 15 shows the relation between lime dosage and pH. It shows that this method of control is feasible on this water because the adjustments on the slaker are fine enough that small enough dosage changes can be made to closely control pH, especially in the lower pH range.

The secondary treatment was reasonably consistent throughout the various phases but it is not especially good secondary effluent. Most of the problems occurred with the control of the secondary clarifiers and the settleability of the sludge. There was little nitrification in the secondary plant and the nitrogen situation was little changed by tertiary treatment. Suspended solids, volatile suspended solids, turbidity, BOD, COD, COD filtrate, color and methylene blue active substances for the secondary effluent are all summarized for each phase in Table 4. The changes in these parameters resulting from lime treatment and filtration can also be seen in the Table. There were substantial BOD and COD reductions.

The temperature in the reactor-clarifier in the coldest part of the winter was 20 - 22°C and in the hottest part of the summer it was 28 - 30°C.

The variations in calcium, magnesium and hardness were also observed. There is little softening of the water by using a single stage recarbonation. The hardness decreased by 10 percent with the higher lime dosages. The calcium ions increased some and the magnesium ions decreased. Note there is a large decrease in magnesium ions in the 10.5 to 11 pH range but also that there is some decrease in magnesium ions in the 9.5 to 10 pH range.

The orthophosphate analysis was made on a filtered sample. Therefore the reactor-clarifier effluent sample should have the same orthophosphate value as the filter effluent sample unless the recarbonation step had an influence. Since the filter effluent often showed increased soluble orthopohsphate, some precipitated phosphate was being redissolved in the recarbonation. Culp and Culp (8) state that calcium carbonate is not redissolved in recarbonation but that magnesium salts are probably releasing some adsorbed phosphate. Therefore where the maximum phosphate removal is desired, more careful control of recarbonation than manual setting of the CO_2 producer may be necessary. A neutral pH may be better for downstream carbon adsorption and chlorine disinfection and produce less sludge in the recarbonation tank but with a slightly higher effluent phosphorus concentration.

Single stage phosphorus removal seemed suitable at Santee. The amount of alkalinity is in the 200 mg/l range and calcium about 90 to 95 mg/l. This amount of alkalinity is in the lower part of the suitable range,

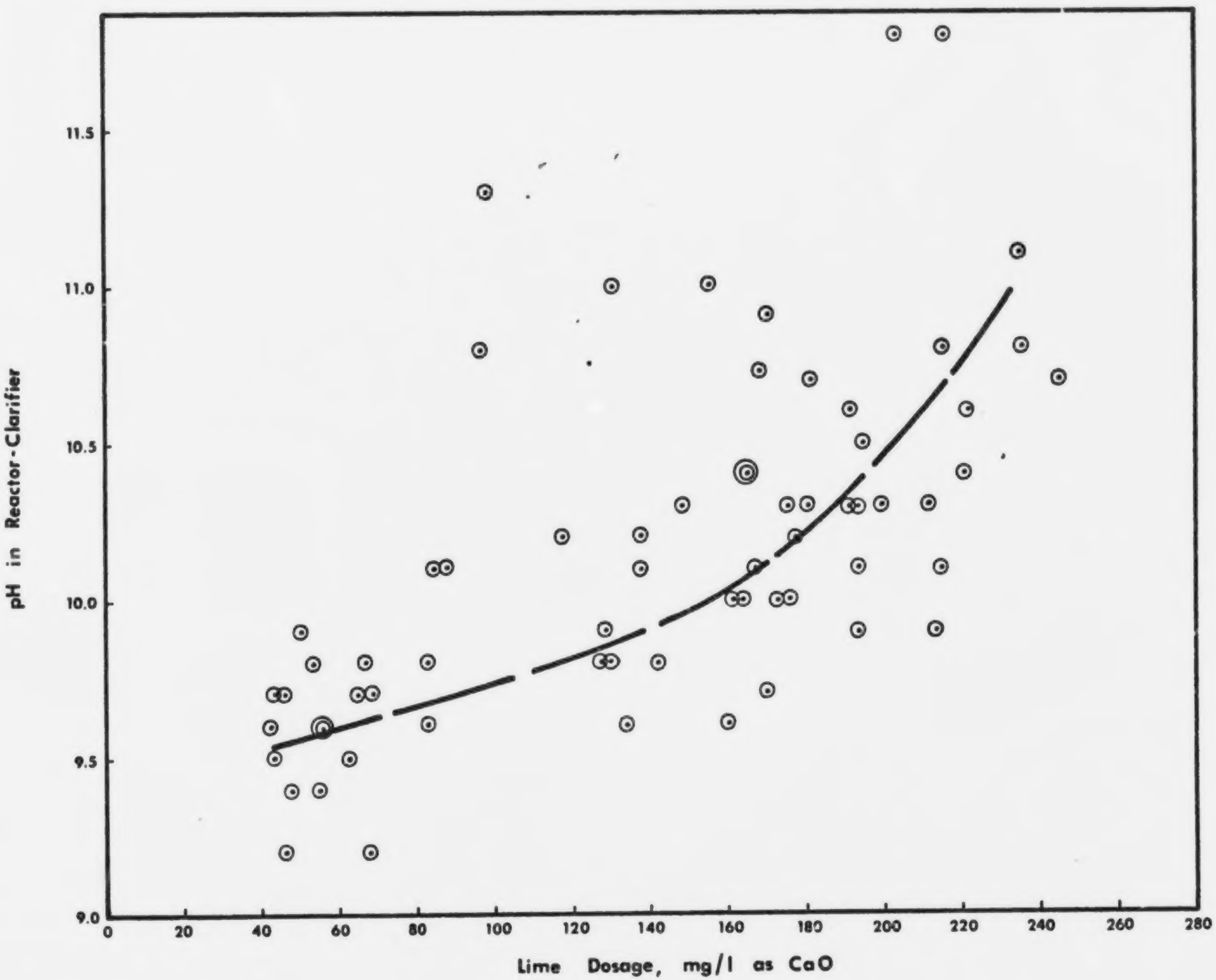

FIGURE 15. LIME DOSE vs. pH IN REACTOR-CLARIFIER

but when combined with the unusually high amount of calcium, there apparently is quite an adequate calcium carbonate precipitation to weight the floc. Polyelectrolyte will always be used because with only a small dosage the operation is more easily controlled and the visual appearance improved. Single stage recarbonation is desired for less sludge production and lower cost. Hardness removal is not important at this time. The higher ranges of pH in the reactor-clarifier will be used because high phosphorus removal is necessary at Santee. However sustained removals of greater than 80 percent have been achieved with only a dosage of 60 mg/l.

The solids concentration in the sludge blanket was determined from a grab sample taken from a valve one foot above the tank bottom at the side wall. The results are given in Table 5, along with the total solids in the sludge discharge line. The irregularity in these values was partially intentional as the operators were trying to learn the effects of varying the sludge blanket and how to control it. The blanket could be moved up and down by changing the turbine speed so some days the densest portion of the blanket might not be at the one foot valve. Therefore the values are only guides to the concentrations which can be obtained. They cannot be correlated with performance. The average would not necessarily be the average sludge concentration. Sludge wastage was difficult to regulate with the interval timers and almost impossible manually so a constant concentration was not maintained. However, the sludge can be thickened to high concentrations in the reactor-clarifier and can be removed in high concentrations to the sludge beds.

DUAL MEDIA FILTERS

During the design stage it was discussed whether recarbonation and filtration were necessary at Santee, since the plant was followed by a large holding lagoon before the recreational lakes. It was decided to add the filtration step to have greater clarity of water in case the lagoon would be eliminated at some future time and the public would have direct access to the plant effluent. The filtration would be a safety backup in case of solids carry over from the reactor-clarifier. It was expected that filtration and chlorination would provide a water which would meet public health standards for recreational lake purposes. Also filtration was considered necessary before the carbon adsorption pilot plant.

The filtration process however did not perform well, even during period one (Day 145-240, 1970) when the flow was very constant and the media were new. The suspended solids and turbidities remaining in the effluent were high and the percent removals were low as shown in Table 6. (Although the turbidity is within the limits accepted by the drinking water standards, this level of turbidity is not expected in filtered drinking water.) The phosphorus removal was not improved by recarbonation and filtration as was shown in Table 4. Since Santee does not now

TABLE 5 SOLIDS CONCENTRATION IN REACTOR-CLARIFIER

grab samples, solids in blanket sampled one foot above bottom at side well.

Day	Total Solids In Blanket mg/l	Total Solids In Sludge Discharge mg/l
1970		
231		31,145
233		42,150
238		31,620
240		22,324
317		165,450
324		106,480
329		27,180
331		25,305
336		8,870
338		18,090
343		23,485
345		27,010
352		22,360
355		5,650
357		14,165
364		61,480
1971		
6		18,840
8		7,210
13		6,385
15		7,800
20		12,140
27		4,485
29		17,860
34		120,925
36		64,825
41		40,200
48		120,540
50		190,835
55		36,385
57		156,700
62		44,620
64		118,020
69		23,415
71		23,380
76		60,330
78		8,730
83		27,370
85		32,440
90		14,075
92		24,150
97	4,640	14,800
99	6,340	20,040
104	1,410	39,695
106	21,255	42,070
111	17,730	45,940
113	7,390	25,665
120	5,275	22,300
125	7,780	10,515
127	7,280	14,580
132	29,720	40,000
134	27,115	49,170
139	24,200	67,700
141	66,965	72,390
146	53,175	76,830
148	5,365	20,210
153	13,925	22,110
155	2,125	34,710
160	25,670	29,245
162	23,660	31,480
167	36,700	11,670
169	79,830	65,315
174	63,185	20,360
176	52,660	23,850
181	250,330	187,440
183	78,300	160,820
188	3,165	10,055
190	7,600	59,000
195	1,870	34,275
197	13,070	39,525
211	8,375	273,365
216	63,230	76,330
218	60,685	10,660
223	1,440	53,915
225	1,865	39,680
237	1,485	51,500
239	1,272	63,600
242	1,275	46,130

but when combined with the unusually high amount of calcium, there apparently is quite an adequate calcium carbonate precipitation to weight the floc. Polyelectrolyte will always be used because with only a small dosage the operation is more easily controlled and the visual appearance improved. Single stage recarbonation is desired for less sludge production and lower cost. Hardness removal is not important at this time. The higher ranges of pH in the reactor-clarifier will be used because high phosphorus removal is necessary at Santee. However sustained removals of greater than 80 percent have been achieved with only a dosage of 60 mg/l.

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TABLE 5 SOLIDS CONCENTRATION IN REACTOR-CLARIFIER
(continued)

grab samples, solids in blanket sampled one foot above bottom at side well.

Day	Total Solids In Blanket mg/l	Total Solids In Sludge Discharge mg/l
245	1,610	93,120
253	2,210	98,260
257	20,480	34,935
260	8,000	13,000
264	2,250	6,310
266	1,695	4,720
271	2,405	5,310

intend to replace the holding lagoon, and because of operating difficulties and lack of significant improvement in the water quality from these units, it is concluded that the recarbonation and filtration processes are not necessary to meet present Santee water quality goals. They would of course, have to be included if demineralization were added on plant scale.

The two twenty-two foot diameter filters were to handle a design flow of 2 mgd for a nominal rate of 2 gpm/ft^2, actual 1.83 gpm/ft^2. While backwashing one filter, about 45 minutes, the other filter takes the entire flow. Therefore for short periods the filtration rate is rapidly doubled on one filter. During operation the filtration head builds up in the vertical inlet pipe as the filters become dirty so with greater head a constant flow is maintained. The filter is backwashed when the head reaches a set value. No chemical treatment was used after recarbonation to prepare the water for filtration and no chemicals were used during filtration. Provisions were made in the design for chemical treatment but it is not normally used at such low filtration rates. No tests were made at Santee to select the media. This combination of anthracite and sand is the media usually recommended by Eimco Corporation, Salt Lake City, for this operation.

The main focus of the tertiary project was not the filters, since previous studies have shown that good filtration can be obtained on lime treated waters at low filtration rates. Operations were handicapped by a lack of operating head and damaged control panels. In the tertiary plant layout sufficient headloss was not allowed for through the recarbonation basins. This meant the plant could not operate at 2 mgd. A relocation of piping allowed full design flow but with a sacrifice of 2.7 feet of filter operating head. This meant more frequent backwashing. After the automatic control panels were abandoned on Day 105, 1971, the filters were washed manually when convenient. If the head exceeded 2½ feet an overflow into the backwash occurred until a back-

TABLE 6 FILTER PERFORMANCE

SUSPENDED SOLIDS, mg/l

Day	Filter Influent	Filter Effluent	Percent Removed
145-240, 1970	23	15	35
316,1970-59,'71	42	34	19
60-145, 1971	26	23	12
146-225, 1971	80	30	62

TURBIDITY, units (JTU)

Day	Filter Influent	Filter Effluent	Percent Removed
145-240, 1970	1.2	1.2	0
316,1970-59,'71	8.6	4.0	53
60-145, 1971	3.7	2.7	27
146-225, 1971	14.3	2.9	80

wash was made. For the last two months of the study program, it was decided to give special emphasis to the filters and try to find the reasons for the poor performance shown in Table 6. The regular testing program on the tertiary plant, with composite samples, was stopped and a minimum grab testing program was substituted to monitor the reactor-clarifier.

Only the North filter was studied. The flow in the plant was about 1 mgd during this period so the filter rate was a nominal 2 gpm/ft^2. Both filters seemed to be in similar condition. By eliminating one filter, there were no uncertainties about overflows at the end of a run going into the other filter. At 1 mgd the full five feet of design head is available. While backwashing the flow is backed up in the CO_2 basins and then goes out the splitter box overflow.

By the time these tests were made, the filter media were not in good condition and about half of the anthracite had been washed away. The media are out of sight, under the backwash compartment, and are easily ignored. An inspection showed large lumps of lime coated anthracite throughout both layers, even to the bottom. Most lumps were ¼" to 3/4" in diameter with a few large pieces ½" thick and several inches across. Also there were many flat platelets of calcium carbonate, a quarter to a half inch across. The individual grains of anthracite did not appear to be coated. There was no slime, biological growth or balls or organic material or mud. Both filters appeared the same.

It appeared that a heavy calcinated layer had formed on the filter at some time. This layer had then been broken up. There had been problems with the CO_2 producer cycling on and off, therefore passing slugs of high pH water to the filters. This unstable water will deposit calcium carbonate on the filter grains. When the CO_2 producer was down for a long period, the filters were bypassed but not drained. Therefore they sat in high pH water. Before polyelectrolyte was used in the reactor-clarifier, the sludge blanket was occasionally discharged. If the discharge was observed then the filters were bypassed. Some combination of these circumstances probably led to the lime coating. From Day 207 to Day 210, the CO_2 producer was operated at maximum and no lime was added, this produced a pH between 6 and 7. That did not seem to affect the lime coating. No acid treatment was made.

For the last six weeks of the study, the performance on all filter runs during the weekdays are shown in Table 7. The gallons in a run, the running hours, and the increase in head during that run were observed. The amount of testing was limited to some turbidity measurements. Therefore the turbidity of the influent was taken at the end of the run to see if there were some unusual conditions in the influent causing early termination of that run. The filter effluent turbidity was taken in the middle of the run for those runs during the day shift and at the end of each run to see if there had been a turbidity breakthrough.

The night shift at the plant was discontinued before these tests were started. Therefore the night runs were terminated early each morning regardless of the head and a new run was started. The day's run was to go as near to maximum head as possible. This usually went to the evening shift. The evening operator would backwash again before he left if he felt the plant would not make it to morning without using all available head and overflowing. Since the flow meter measured the influent, not the discharge, care had to be taken to not exceed maximum head which would bypass the filter to the overflow. These procedures resulted in the filter being followed continuously through the week. There were no breaks in the observations. It also resulted in

TABLE 7 DUAL-MEDIA FILTER TESTS, PART 1

Day	Run Number	Gallons In Run	Hours In Run	Increase In Head During Run-Feet	Turbidity Filter Influent @ End of Run	Turbidity Filter Effluent Middle of Run	Turbidity Filter Effluent End of Run
	---	---	---	---	6.6	---	---
236	1	637.000	14:45	---	11	3.9	2.2
236-237	2	406,000	9:25	5.7	11	---	2.0
237	3	229,000	4:10	5.0	---	---	---
237	4	512,000	10:25	1.6	8.2	4.8	4.8
237-238	5	456,000	9:30	0.5	6.3	---	3.6
238	6	773,000	15:30	4.0	6.4	2.6	3.5
238-239	7	422,000	8:45	0.7	5.5	---	3.2
239	8	733,000	14:45	3.8	9.5	1.7	3.4
242	9	689,000	14:10	2.2	4.2	2.1	1.3
242-243	10	455,000	9:30	2.2	3.3	---	1.4
243	11	531,000	12:30	5.0	4.0	1.2	1.1
243	12	205,000	3:00	2.2	---	---	---
243-244	13	344,000	8:30		6.0	---	1.7
244	14	576,000	11:40	5.1	15.0	1.0	1.2
244	15	183,000	4:00	0.9	---	---	---
244-245	16	379,000	8:20	0.4	6.1		17.0
245	17	487,000	11:00	5.0	6.1	1.1	1.2
245	18	212,000	4:30	0.5	---	---	---
245-246	19	401,000	8:50	0.3	3.4	---	1.3
246	20	632,000	13:40	5.4	6	1.3	1.2

TABLE 7 DUAL-MEDIA FILTER TESTS, PART 1 (continued)

Day	Run Number	Gallons In Run	Hours In Run	Increase In Head During Run-Feet	Turbidity Filter Influent @ End of Run	Turbidity Filter Effluent	
						Middle of Run	End of Run
	---	---	---	---	9.0	---	---
250	21	441,000	8:50	5.5	7.4	1.1	5.0
250	22	320,000	6:30	5.3	---	---	---
250-251	23	409,000	9:00	3.0	7.6	---	2.2
251	24	715,000	14:35	3.4	7.4	1.9	2.0
251-252	25	436,000	9:25	0.6	3.7	---	1.8
252	26	736,000	15:00	3.1	6.0	1.4	1.8
252-253	27	420,000	9:00	---	5.1	---	2.5
253	28	683,000	14:30	2.1	50.	1.6	2.4
	---	---	---	---	5.7	---	---
256	29	632,000	13:20	0.5	6.5	5.5	3.1
256-257	30	438,000	9:30	1.1	3.6	---	1.7
257	31	479,000	10:30	5.1	4.1	1.2	1.7
257	32	210,000	4:30	1.8	---	---	---
257-258	33	395,000	8:50	3.1	2.5	---	1.5
258	34	357,000	8:40	5.4	8.7	1.7	1.8
258	35	344,000	6:30	4.3	---	---	---
258-259	36	398,000	9:00	5.8	3.9	---	1.7
259	37	236,000	5:00	4.6	6.0	---	1.7
259	38	258,000	5:30	4.4	6.1	1.3	1.5
259	39	256,000	5:30	5.1	5.0	---	1.7
260	40	232,000	5:00	---	6.1	---	1.6
260	41	252,000	5:20	---	8.2	---	1.4

TABLE 7 DUAL-MEDIA FILTER TESTS, PART 1 (continued)

Day	Run Number	Gallons In Run	Hours In Run	Increase In Head During Run-Feet	Turbidity Filter Influent @ End of Run	Turbidity Filter Effluent Middle of Run	Turbidity Filter Effluent End of Run
	---	---	---	---	4.3	---	---
263	42	478,000	9:40	5.1	9.5	2.7	2.5
263-264	43	422,000	9:30	5.7	5.7	---	1.8
264	44	366,000	8:20	4.1	6.1	1.6	1.9
264	45	302,000	7:00	4.8	---	---	---
264-265	46	370,000	9:00	4.4	4.8	---	1.4
265	47	631,000	13:00	4.9	---	1.3	---
265	48	114,000	2:00	0.9	---	---	---
265-266	49	374,000	8:40	4.9	4.5	---	1.2
266	50	297,000	6:05	4.0	4.8	---	1.6
266-267	51	680,000	18:05	2.9	6.2	---	2.3
267	52	567,000	13:40	4.9	6.0	2.4	1.9
	---	---	---	---	---	---	---
270	53	446,000	8:50	4.2	10.+	2.2	3.4
270	54	278,000	6:00	5.3	---	---	---
270-271	55	404,000	9:30	5.3	3.8	---	2.2
271	56	513,000	10:20	3.4	10.0	2.2	1.8
271	57	---	---	2.5	---	---	---
271-272	58	---	---	5.4	7.4	---	4.1
272	59	377,000	8:30	4.6	7.8	4.6	4.5
272	60	292,000	6:45	---	---	---	---
272-273	61	364,000	8:15	---	10.0	---	1.9

TABLE 7 DUAL-MEDIA FILTER TESTS, PART 2

Run Number	Backwash at End of Run Minutes of Air Agitation	 Minutes for Tank to Drain	Turbidity of Backwash Water Beginning of Backwash	 End of Backwash
---	6	3:60	37	12
1	6	4:05	95	15
2	6	3:50	21	10
3	6	3:50	---	---
4	6	3:50	95	20
5	6	3:55	53	22
6	6	3:55	95	30
7	6	3:50	40	18
8	6	3:40	75	20
9	---	---	61	25
10	6	3:33	25	9
11	6	3:41	28	10
12	---	---	---	---
13	6	3:33	14	8.5
14	6	3:40	100+	75
15	---	---	---	---
16	6	3:30	21	20
17	6	3:40	55	150
18	---	---	---	---
19	6	3:32	38	15
20	6	3:40	100+	30

TABLE 7 DUAL-MEDIA FILTER TESTS, PART 2 (continued)

Run Number	Backwash at End of Run Minutes of Air Agitation	 Minutes for Tank to Drain	Turbidity of Backwash Water Beginning of Backwash	 End of Backwash
---	6	3:40	57	22
21	6	3:45	100	60
22	---	---	---	---
23	6	3:33	24	7
24	6	3:40	55	15
25	6	3:33	34	10
26	6	3:40	85	15
27	6	3:55	28	13
28	6	3:40	40	140
---	6	3:50	62	25
29	6	3:47	65	20
30	10	3:20	50	12
31	10	3:20	60	15
32	---	---	---	---
33	10	6:15	29	7
34	10	6:20	---	32
35	---	---	---	---
36	10	3:15	28	10
37	10	3:12	27	11
38	10	4:00	35	14
39	10	3:08	33	10.3
40	10	4:00	39	10.4
41	---	---	---	---

TABLE 7 DUAL-MEDIA FILTER TESTS, PART 2
(continued)

Run Number	Backwash at End of Run		Turbidity Backwash Water	
	Minutes of Air Agitation	Minutes for Tank to Drain	Beginning of Backwash	End of Backwash
---	30	3:20	12	12
42	---	---	80	50
43	10	3:00	21	9
44	10	3:10	30	10
45	---	---	---	---
46	10	3:20	22	10
47	10	3:15	---	---
48	---	---	---	---
49	10	3:00	33	13
50	10	3:40	57	21
51	10	3:10	42	16
52	10	3:54	53	19
---	10	3:00	46	15
53	10	3:00	100	39
54	---	---	---	---
55	10	3:10	77	42
56	10	3:00	70	30
57	---	---	---	---
58	10	3:10	95	45
59	---	---	100	45
60	---	---	---	---
61	10	3:15	57	21

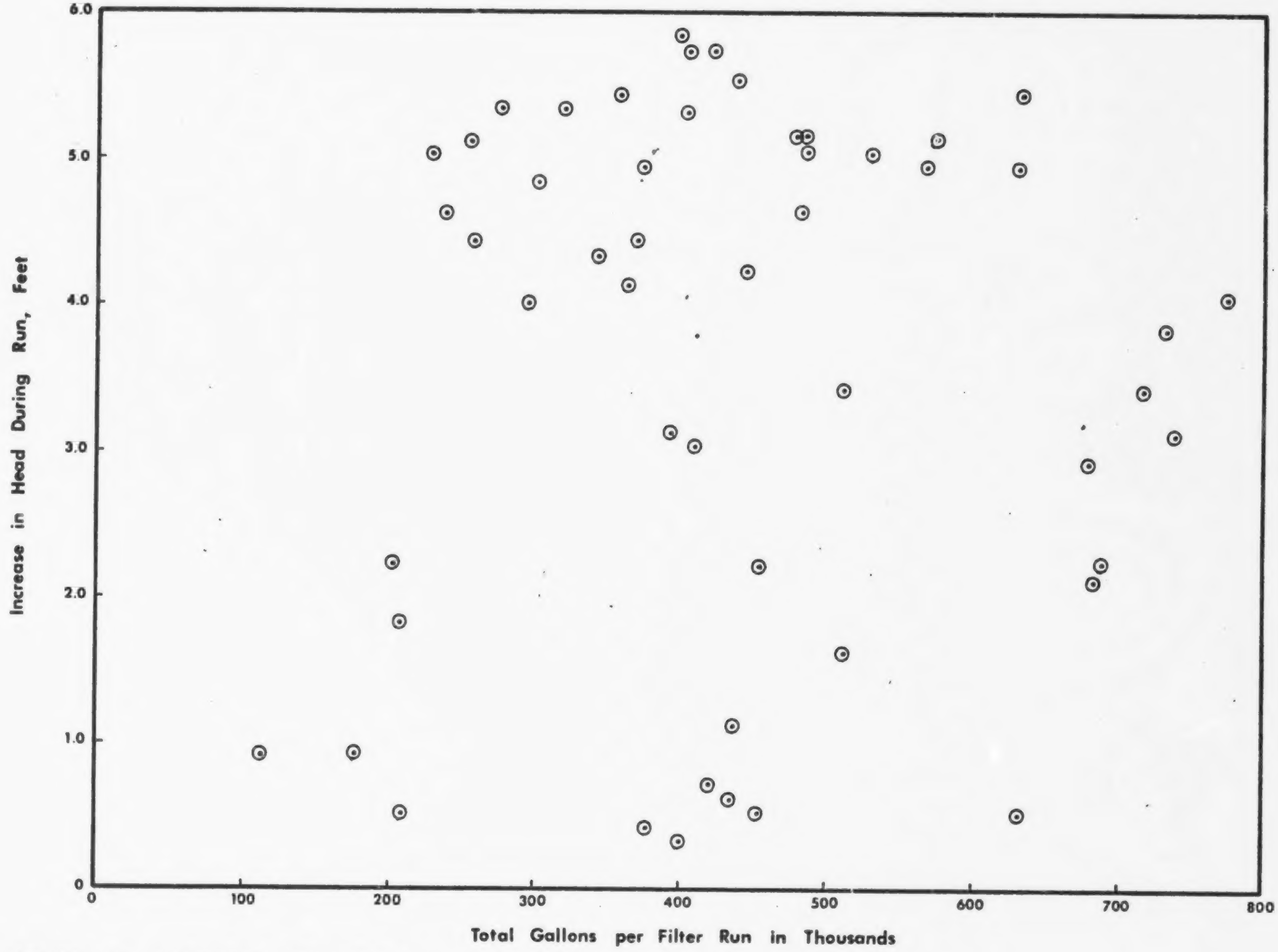

FIGURE 16. INCREASE IN HEAD vs. GALLONS FILTERED

a large variety of run lengths. The increase in head versus the gallons filtered is shown in Figure 16. There appears to be no relation between them. The influent flow rate was about constant day and night, day after day. There were no unusual occurrences in plant operations. The variations in influent turbidity do not indicate large changes in the solids content of the water. Obviously this is not a normal filtration result. The average length of the runs is independent of the increase in head during the run. Therefore the increase in head is not being caused by removal of materials from the water. Perhaps this random change in resistance resulted from the deteriorated condition of the media.

An operator was available during the night of Day 259 so it was decided to follow the runs in more detail by taking a product turbidity every hour and a pressure reading every half hour. The head built up rapidly on this day and five runs were accomplished in a twenty-six hour period. The results are given in Appendix C. The reactor-clarifier performance at this time was good and the effluent quality comparatively clean as can be seen in Appendix B, Table B-5. The filter performance during these five runs appears reproducible and rather typical. The turbidity was a constant 1.5 to 2 units through the run, breakthrough was not observed.

The backwash information is also tabulated in Table 7. Six minutes of air agitation was used in the first three weeks and ten minutes in the last three weeks. There was much concern about backwash rates and that the irregular run lengths were due to incomplete backwashing. The filter manual supplied by the manufacturer states the maximum rate of backwash should be 22 gpm/ft^2 or a lowering of the first foot in the backwash compartment in about 20 seconds. Rates less than this had been used during most of the study and yet media had been lost. An average rate of 15 gpm/ft^2 is also mentioned in the instructions. The depth of water available for backwashing is about six feet which would make the time of backwash about three minutes for a 15 gpm/ft^2 rate. The actual time to drain the tank is shown in Table 7. It can be seen that this maximum was not exceeded but the rates were near those recommended. The seconds required for the first foot were measured as follows: Day 238: 30 sec., Day 242: 22 sec., Day 251: 23 sec., Day 256: 22 sec., Day 271: 24 sec. The turbidity of the backwash water was taken at the beginning and end of each cycle. The average production per run was 430,000 gallons and the amount of backwash water is 17,000 gallons, so 4 percent of product went to backwash.

From this testing it appears that the media and depth selected for this application were not correct. Media cannot be selected from theoretical considerations. Testing is required to select the proper combination. The media design used was developed by Eimco at other locations. Anthracite and sand media have performed well in this kind of application, however the performance here was not good even from the first tests and it did worsen some with time. A low filtration rate is no guarantee that a poorly selected media will perform well and pilot tests are suggested regardless or previous experiences at other locations.

SECTION V

COSTS AND RELATED FACTORS

The cost of sewage treatment consists of a construction cost, which can be calculated on an annual basis by amortizing over a number of years, and operation costs which are usually calculated per unit of sewage treated. The operating costs can be further broken down into direct manpower charges and overhead to cover supporting services, charges for utilities and chemicals, and charges for the purchase of outside maintenance services, equipment, and materials. The actual expenses incurred in these various categories at Santee have been tabulated and are reported in the first subsection.

It was intended that the operations at Santee would be representative of normal sanitary district operations. However, a number of design and operating problems, the need to make a demonstration study of the plant, and the lack of experience with this type of plant make the actual expenses more indicative of initial start-up costs than normal long term costs. These unusual circumstances are further illustrated in the Reliability Subsection by the percent of time that the various units operated. Therefore the Project Engineer, based on the Santee experiences and discussions with plant personnel, has adjusted the actual expenses to make an estimate of the cost of operating this plant under efficient, routine circumstances.

ACTUAL EXPENSES

The time cards of the treatment plant staff were analyzed to determine the man hours spent on tertiary treatment operation. Table 8 begins in April, 1970, (Day 91) and goes to the end of February, 1971, (Day 59). During that period, time was reported for tertiary without breakdown per unit process. The average was 343.5 hours per month. This includes all activities by the operational staff including training, some modifications, and special work because of the study program. The foremen time is included but not time for the project laboratory, plant superintendent, or project engineer. Throughout the period of this report, no analytical work was done on tertiary treatment by the plant's regular laboratory.

Table 9 covers the period from March 1, 1971, (Day 60) to the end of the study program September 30, 1971, (Day 273). The time is reported for the same employees as above so a comparison can be made. During this reporting period, the time was broken down according to unit processes. Since some of the same employees participated in both operations and maintenance, the time cannot be separated into those two areas. Note that the average time reported per month increased by forty-four percent. This increase was due to more careful accounting of time with the expanded reporting system rather than increased work loads. Previously night shift personnel were not reporting the time

TABLE 8 ACTUAL MANHOURS IN TERTIARY TREATMENT

Pay Period	Hours
1970	
4/1 - 4/15	152
4/16 - 4/30	149.5
5/1 - 5/15	139.5
5/16 - 5/31	116
6/1 - 6/15	148
6/16 - 6/30	133
7/1 - 7/15	89
7/16 - 7/31	102
8/1 - 8/15	116
8/16 - 8/31	151.5
9/1 - 9/15	295.5
9/16 - 9/30	312.5
10/1 - 10/15	195
10/16 - 10/31	166.25
11/1 - 11/15	131.5
11/16 - 11/30	248
12/1 - 12/15	182
12/16 - 12/31	261.5
1971	
1/1 - 1/15	79.5
1/16 - 1/31	159.25
2/1 - 2/15	269
2/16 - 2/28	182
Average/Month	343.5

Operation and maintenance manhours, including foreman. Not included are project laboratory, Plant Superintendent, or Project Engineer.

TABLE 9   ACTUAL MANHOURS PER UNIT PROCESS

Pay Period	Reactor-Clarifier	Slaker	Recarbonation	Dual-media Filters	Miscellaneous	Administration	Total
1971							
3/1 to 3/15	73.25	44.75	30.50	20.25	33.75	15.25	217.75
3/16 to 3/31	63.75	27.25	31.25	127.50	58.00	28.00	335.75
4/1 to 4/15	82.00	38.00	46.25	57.50	66.75	14.50	305.00
4/15 to 4/30	78.75	90.25	20.75	90.00	70.25	21.00	371.00
5/1 to 5/15	42.50	45.00	30.25	50.50	70.75	18.25	257.25
5/16 to 5/31	77.00	44.00	16.50	42.00	73.25	6.50	259.25
6/1 to 6/15	70.75	39.00	16.50	47.00	88.00	16.50	277.75
6/16 to 6/30	67.75	42.00	23.75	33.75	59.25	16.50	243.00
7/1 to 7/15	41.00	25.75	22.25	40.00	57.50	17.00	203.50
7/16 to 7/31	40.00	54.00	12.75	40.75	66.25	13.00	226.75
8/1 to 8/15	41.75	24.00	11.25	45.25	51.25	15.50	189.00
8/16 to 8/31	32.50	43.25	13.50	43.25	52.50	13.25	198.25
9/1 to 9/15	35.25	36.50	12.25	49.50	65.00	7.00	205.50
9/16 to 9/30	25.25	29.25	8.25	54.25	40.25	14.25	171.50
Average/Month	110.2	83.3	42.3	105.9	121.8	30.9	494.5

Operation and maintenance manhours, including foremen. Not included are project laboratory, Plant Superintendent or Project Engineer.

they spent checking pH and inspecting the plant. Therefore the totals in Table 9 are more representative of actual time spent.

Included in Table 9 under the reactor clarifier column was work on the polyelectrolyte feeding system and the sludge drying beds. However the plant crew did not clean the sludge beds. Therefore the cost of sludge removal and disposal is separate and described later. Since the lime feeder and slaker were major maintenance jobs, they are reported separately. Maintenance of the sample stations is included under the appropriate unit process. Most of the time under "miscellaneous" was wash down and general cleanup in the tertiary area. Administration includes time keeping and record keeping, ordering supplies, telephone, and meetings. Operators were assigned specially to tertiary only on the day shift, five days a week. At other times the duty operator would periodically check the tertiary plant. From the beginning of the project through August 19, 1971, (Day 231), an operator was on duty for the entire treatment plant twenty-four hours per day, five days a week and eight hours per day on weekends and holidays. A watchman was there sixteen hours per day on weekends and holidays. For the last forty-two days of the study, there were operators on duty sixteen hours per day and the plant was unattended eight hours per day, five days per week. The weekends and holidays remained the same.

The electric power requirements for the tertiary plant are given in Table 10. The entire influent for the tertiary plant was pumped against the head of about twenty feet. The waste recycle pump supplemented the lower night sewage flows with secondary effluent from Lagoon A so that a constant flow of two mgd could be maintained in the tertiary plant. Considerable extra lighting for safety was added during construction since the plant is in a remote location and the night operator is there alone.

The only use of natural gas in the tertiary area was by the CO_2 producer and the amount was determined from its gas meter. Over a period of 322 days (Day 316 to 273), 1,385,000 cubic feet of gas were consumed. During this period the time clock on the CO_2 producer indicated it operated 81.2% of the time. Therefore the average gas consumption for a twenty-four hour day was 5,300 cubic feet.

The costs for maintenance materials and outside services directly concerned with maintenance were determined by adding the invoices from March, 1970, through September, 1971. Not included were plant chemicals, power, sludge disposal, plant vehicles, and office supplies. These items are charged separately or are included in the overhead. Many of the charges during this period were due to correcting problems of an unusual nature or extra work due to the study program. Therefore the invoices were sorted and it was determined that the average monthly charge for normal circumstances would be $350.00 per month. The actual direct charge was $630.00 per month. This is a two-fold increase but of course, such a difference would not be sustained over many years since

TABLE 10 POWER REQUIREMENTS

Item	Horsepower	Kilowatt-hours/day
Tertiary Influent Pump	15	
Lime Ejector Feed Pump	5	
CO_2 Producer Compressor	7.5	
Waste Recycle Pump	30 (8 hr./day)	
Miscellaneous Small Motors	11.5	
Subtotal	69	877
Lights, 5360 watts (12 hr./day)		64
Total		941

the problems would gradually be corrected.

LIME SLUDGE DISPOSAL COST

The disposal of the lime sludge is simple and low cost. The sludge is air dried on a 10,000 square foot bed until it is a hard solid. It is then removed with a front and loader and dump truck and disposed of on District property with a haul of not greater than one mile. There it is just left in spoil piles. Therefore the cost of sludge disposal is just for loading and hauling. The plant personnel as part of their normal cleanup maintenance do some slight work on the banks of the beds. The cost was determined as $62.50 per month by estimating the time it takes to fill one bed (two months) and the work order charges for labor and equipment to clean one bed ($125.00). It was not necessary to purchase land for either the drying beds or disposal areas.

RELIABILITY

The costs of waste treatment are greatly influenced by the smoothness of operations and the reliability of the equipment. The goal is to obtain routine operations, departures from this routine mean additional costs and poorer average performance. Lack of routine was a major problem during the Santee study, making steady operations infrequent, measurements of performance difficult and adding considerably to the labor needed. Therefore the reliability has to be examined in determining what adjustments need to be made to the actual costs to estimate a "normal" situation.

The extent of this problem is shown by Table 11 which is a summary of the hours of operation. The hour meters on the tertiary pump, slaker, and CO_2 producer were used to make these calculations. The time periods covered are from Day 145 to Day 240 in 1970 and from Day 316, 1970, to

TABLE 11 SUMMARY OF HOURS OF OPERATION

Time Period Day Of Year	Hours In Period	Hours Tertiary Pump Operated	Hours Slaker Operated	Hours CO_2 Producer Operated	Percent Time Pump Operated	Percent Time Slaker Operated	Percent Time CO_2 Producer Operated
1970							
145-182	888	834.2	887.9	842.8	93.9	100.0	94.9
182-217	846	809.7	844.4	714.6	95.7	99.8	84.5
217-240	552	541.8	548.1	512.6	98.2	99.3	92.9
294-335	984	876.0	928.8	509.8	89.0	94.4	51.8
335-7	888	860.6	847.3	577.8	96.9	95.4	65.1
1971							
7-60	1272	1196.9	1219.3	1038.1	94.1	95.9	81.6
60-91	744	725.8	742.9	736.6	97.5	99.8	99.0
91-120	696	607.7	617.3	615.2	87.3	88.7	88.4
120-152	768	759.5	751.6	765.0	98.9	97.9	99.6
152-187	840	830.1	835.0	816.5	98.8	99.4	97.2
187-250	1512	1325.9	1263.7	1249.9	87.7	83.6	82.7
250-273	552	504.6	550.2	397.5	91.4	99.7	72.0
Overall	10542	9872.8	10036.5	8776.4	93.7	95.2	83.3

Day 273, in 1971. Not included was the period of reconstruction between Day 240 and Day 316 in 1970. Included in the above periods there was one major down period of one week and several periods of one or two days. However, most of the "down" hours were accumulated by short interruptions in service due to adjustment or small maintenance and cleaning problems. Also there were high failure rates on electric and instrument systems leading to abandonment of some of these control functions after a time.

Reliability is a very serious matter, sophistication in project conception, process development and design will go for nothing if reliability of a high degree is not obtained. At Santee the objective was to show that phosphorus could be removed to a level sufficiently low to control algae growth. If this meant reducing the phosphorus from 10 mg/l to 0.1 mg/l, and if the plant attained this when running but was down one day per month for a reliability of 97%, then the monthly average effluent phosphorus is raised to .43 mg/l. Therefore, even a slight amount of trouble defeats the objective.

A formal, written, periodic maintenance procedure appears essential to keep this kind of plant operating. It should include frequent mechanical and functional inspections, occasional dewatering of units for inspection and maintenance, and keeping a careful equipment repair history. This cannot be left to the initiative of the various shift operators. The plant administrator should develop and enforce such a program. Even in a plant as small as this, the complexity of processes might justify hiring an engineer or chemist overall administrator.

The project engineer felt that the routine maintenance servicing of the equipment was deficient and accounted for most of the down time. A formal servicing program was never developed. Also an expanded stock of spare parts is necessary when a plant is from one to several days delivery time away from the manufacturers. The longer down periods on the plant were usually for lack of parts. It may be possible in many sewage treatment situations to wait until the equipment stops or breaks and then maintain or fix it, but this can't be allowed where the average monthly effluent quality must be very high.

ESTIMATED STAFFING

The actual man hours spent by the Santee staff on tertiary treatment included time for modifications of the plant, extra training and special work for the study program. To prepare a cost estimate for "normal" long term operation, an estimated staffing will be developed based upon the experiences of the past two years. The project engineer, after discussions with plant personnel, believes the tertiary portion of the plant could be staffed in the following manner. The job titles follow those to be published by the Environmental Protection Agency. Four hours per day, seven days a week by an Operator II for process monitoring, control and sampling. Ten hours per week by the Operations

Supervisor to monitor the results. Assignment of a Mechanic II half time (20 hours per week) for daily preventive maintenance, adjustments, cleanup, and periodic maintenance and overhauling. The Chemist would devote about twenty hours per week to tertiary analyses. Administrative work is included in the overhead. This is a total labor of 331 hours per month. As a contingency, one major maintenance per year of 200 hours is added. For this various major trades might be used with an average level of Mechanic II.

To operate with the above staff, it would be necessary to correct some of the deficiencies in the existing equipment or replace it. It is assumed that the training period for both supervisors and operators would be past, and the tertiary plant would be a part of a larger plant where staff could be shared with other processes. The operations could be observed routinely from the main control house with the addition of a pump flow recorder, a turbidity meter or blanket finder for the reactor-clarifier and a turbidity meter for the filter effluent, all reading continuously. Then there would be little need for frequent walks to the tertiary plant for visual inspection. Alarm systems could also be developed to warn of problems. For this estimate, it should be noted that the filters are backwashed automatically. It is assumed that the flow to the reactor-clarifier would remain steady and it could be controlled by lime dosage rather than a specified pH.

If the maintenance is done diligently five days per week, there should rarely be an emergency shut-down. Therefore round-the-clock attendance in tertiary does not seem necessary.

CONSTRUCTION COST

The construction cost of the tertiary plant was determined from the contractor's bid, with October, 1968, prices. The items of the cost are given in Table 12 for a total cost of $341,849. The Sewage Treatment Plant Construction Cost Index of the Environmental Protection Agency for Los Angeles for October, 1968, is 133. For Los Angeles in February, 1972 it is 176. Therefore the updated cost to the time of this report is $452,000.

The plant is amortized over a twenty-five year period using a six percent annual interest. The factor is .0782 or 7.82% per year. The reactor-clarifier and the filters are steel tanks in corrosive environments and have an expected service life of twenty-five years. Some items, such as the recarbonation tanks, control building and piping should last longer; other items such as motors and pump impellers have a shorter life. Short term replaceable items are covered by the direct maintenance charges.

There was no cost for the purchase of land. The existing laboratory was used with no charge to the tertiary plant. There was only part

TABLE 12 CONSTRUCTION COST

Earthwork and Grading	
general site, drying beds	$ 4,000
Reinforced Concrete	
tertiary flow pump box, reactor-clarifier, recarbonation basins, dual media filters, tertiary control building, alum pad, sidewalks	41,000
Yard Piping	
sludge beds	3,800
filtrate line	3,300
tertiary plant effluent	5,000
dual media filter effluent	4,000
miscellaneous	3,000
Sub-total	$19,100
Mechanical Equipment	
tertiary flow pump	$ 2,500
lime storage & feed	20,000
flocculator-clarifier	41,000
recarbonation facilities	16,000
dual media filters	62,000
chemical storage tank	2,500
waste recycle	2,000
other miscellaneous equipment	6,500
Sub-total	$152,500

TABLE 12 CONSTRUCTION COST (CONTINUED)

Miscellaneous	
carpentry & doors	$ 1,650
windows glass & glazing	800
lab furniture	1,800
painting	11,000
accoustical ceiling	200
heating & air conditioning	2,500
miscellaneous iron	2,000
paving	4,500
fencing	4,000
resilient flooring	450
masonry	6,500
lath & plastering	650
roofing	150
finish hardware	350
Sub-total	$36,550
Electrical	$50,000
Change Orders	$5,376
Engineering	$25,683
Inspection	$7,140
Drawing Corrections to "As Built"	$500
TOTAL CONSTRUCTION COST (October, 1968)	$341,849

time inspection by the District staff.

ESTIMATED COSTS FOR 1.5 MGD LIME TREATMENT AND FILTRATION

The costs for the Santee Tertiary Treatment Plant operating under normal circumstances on a flow of 1½ million gallons per day are estimated. The estimate is as shown in Table 13. The total cost is 16.03 cents per thousand gallons. Construction amortization is 40% and operation 60% of the total. The cost of sludge disposal is less than one percent of the total. This exceptionally low cost is due to the year around sunny, dry climate and sufficient land for drying and disposal available without charge.

The necessary operating labor has been discussed above. The wage rates and other prices are the February, 1972, levels. An overhead of 40% is added to the labor costs. Twenty percent of this is for direct fringe benefits. The other 20% is for management, office services, payroll, work rooms, plant vehicles, and such indirect overhead charges. The direct maintenance charges have been discussed above. The amounts of electricity and natural gas used in the tertiary plant place these utilities in the highest volume rate classes. Therefore, there would be no lower price with greater consumption. The prices are from the San Diego Gas and Electric Company. The dosages of lime and polyelectrolyte were chosen for high phosphorus removal. The cost of lime is $19.75 per ton with a delivery charge to Santee from Los Angeles of $10.75 per ton. The cost of polyelectrolyte was $1.80 per pound with a delivery charge from Chicago of $.17 per pound. The fortunate low costs for sludge disposal have been discussed above, also the construction costs.

TABLE 13 ESTIMATED COSTS

Based on a steady 1.5 m.g.d. flow.

	Amount	Unit Price	Cost cents/10^3 Gal.
Operating Labor			
Operations Supervisor	10 hr/wk	$5.50/hr	
Operator II	28 hr/wk	$4.25/hr	
Maintenance Labor			
Mechanic II	20 hr/wk	$4.25/hr	
Mechanic II	200 hr/yr	$4.25/hr	
Laboratory			
Chemist	20 hr/wk	$5.50/hr	
Total Labor			3.65
Overhead		40%	1.24
Direct Maintenance Charges		$350/month	.77
Utilities			
Electricity	941 kwh/day	0.9 cents/kwh	.56
Natuaral Gas	5300 ft^3/day	7.34 cents/ 100 ft^3	.26
Chemicals			
Lime (97% CaO)	200 mg/l	$30.50/ton	2.62
Polyelectrolyte	0.2 mg/l	$1.97/pound	.33
Sub-total			9.44
Sludge Disposal	one drying bed/ 2 months	$125/bed	.14
Operating Cost			9.58
Amortization	$452,000.	6%, 25 yrs	6.45
Total Cost			16.03

SECTION VI

ALGAL GROWTH STUDY

by

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and

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This investigation was conducted by the Environmental Engineering Laboratory of the University of California, Irvine (UCI) under a contract to the Santee County Water District (SCWD). The study was supported by Grant WPRD 5-01-67. Assisting the work were Mrs. Carol Justice, Mrs. Barbara Gittins, James Hunt, Steve Guyon and Richard Appleman.

SECTION VI

INTRODUCTION

With the increasing emphasis on better wastewater treatment and improved quality of receiving waters, there is a strong need to evaluate nutrient removal on treatment processes and the effects of discharges on algae growth in a given environment.

The Santee County Water District (SCWD) has been conducting an Advanced Waste Treatment Demonstration Project for the Environmental Protection Agency during the past two years. The demonstration project included phosphate removal by means of lime treatment, and two demineralization processes, ion exchange and electrodialysis. There was also a ground percolation system in existence (1) from a previous study project.

When considering potential eutrophication problems, emphasis has been on the use of chemical analyses to determine the efficiency of treatment processes. However, because of the yet incomplete understanding of the relationship between chemical composition of and biological (algal) response to a discharge, it is likely that conclusions drawn from chemical compositions may not be adequate to guide process design or process modification.

The SCWD, as part of its overall plan of investigation of the treatment process performed comprehensive chemical evaluations of the effluents. Because of the lack of understanding of the effect of chemical composition of a given effluent on algal growth as mentioned above, it was decided to supplement SCWD's chemical evaluation with a detailed investigation of the responses of algae to the types and qualities of effluent produced on certain days i the demonstration project.

GENERAL OBJECTIVES

The general objectives of the investigation conducted at UCI were:

1. To evaluate the relative and absolute effectiveness of the tertiary treatment processes with respect to removal of algal nutrients, and
2. To determine the probable response of artificial lakes and water reservoirs to the tertiary effluents from these treatment processes.

SPECIFIC OBJECTIVES

The specific objectives of this investigation were:

1. To determine the growth limiting inorganic nutrient(s) in:
    a. Secondary (act. sludge) Effluent.
    b. Tertiary (lime treated) Effluent.
    c. Electrodialysis Effluent.
    d. Secondary Effluent after Ground Percolation.
2. To determine the sustained level of algal growth under standard laboratory conditions in continuous culture for:
    a. Secondary (act. sludge) Effluent.
    b. Tertiary (lime treated) Effluent.
    c. Electrodialysis Effluent.
3. To determine the level of algal growth in study ponds for the secondary and tertiary effluents.
4. To compare the laboratory and study pond results and determine if laboratory tests can be used to predict the response of an artificial lake when receiving a given effluent.

METHODS AND PROCEDURES

Sampling

Samples were collected at the Santee Treatment Plant in February, June and August 1971. The sample points are shown in Figure 17. The sample collection corresponded to specific modes of plant operation as indicated in the schedule shown below.

Secondary Effluent (1) Grab sample from inlet pipe to tertiary lime reactor-clarifier on 26 February 1971. A sample representative of normal secondary effluent. (2) 24 hour composite sample from inlet pipe to tertiary lime reactor-clarifier, on 21 - 22 June 1971. A sample representative of secondary effluent and typical influent to the tertiary plant.

Tertiary Effluent (1) Grab sample of tertiary discharge after phosphate removal, pH adjustment and sand filtration on 26 February 1971. (2) Composite sample over 24 hour period from the lime reactor-clarifier. No pH adjustment has been made at this point in the treatment process and pH of this effluent was 9.8. (3) Grab sample after pH adjustment and filtration. The sand filters were back-washed for 1/2 hour

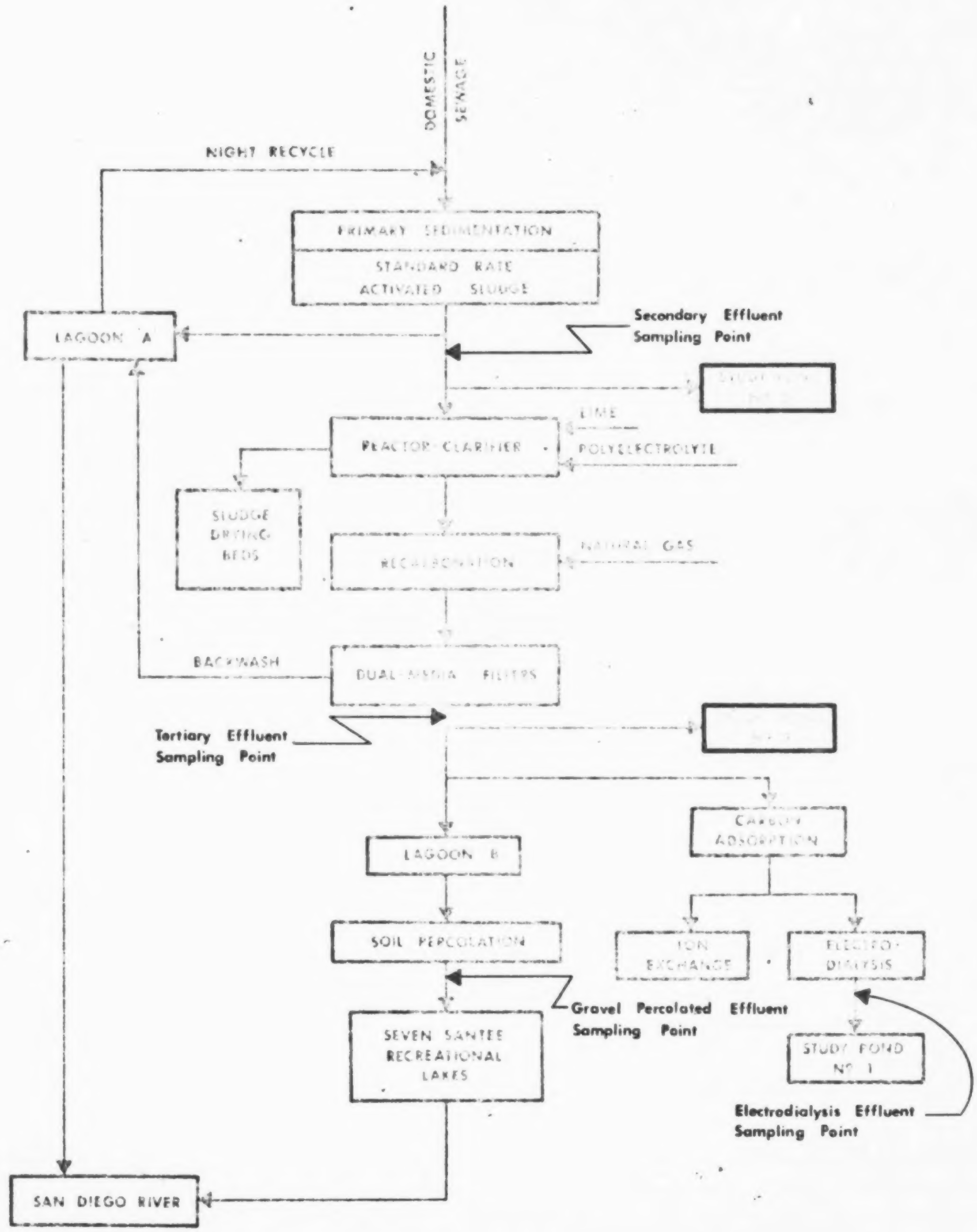

FIGURE 17. ALGAE GROWTH STUDY SAMPLING POINTS

before the sample was collected. This sample representative of typical effluent from the tertiary plant.

Electrodialysis Effluent (1) Composite sample collected after lime treatment recarbonation, filtration, carbon adsorption and electrodialysis.

Ground Percolated Effluent (1) Grab sample after tertiary treatment, lagoon detention and normal percolation of 400' in sand and gravel (cn 21 June).

Samples were collected from Santee in Pyrex bottles, autoclaved and stored in the dark at 4 ± 1°C until used. The four 5 gallon samples of each effluent were thoroughly mixed before autoclaving.

Sample Pretreatment Except for autoclave sterilization the samples were not pretreated as previous studies have shown pretreatment procedures to have a significant effect on the amount of biomass produced.

Batch Algal Assays

The batch algal assays used to determine growth limiting nutrients as well as maximum specific growth rates and maximum standing crop were conducted in accordance with the "Algal Assay Procedure: Bottle Test (1971)" (AAP). A typical batch assay unit is shown on Figure 18.

Test Organism

The algal species used throughout this investigation was *Selenastrum capricornutum* Printz as recommended in AAP. Stock cultures were plated several times to minimize bacterial contamination and maintained in the standard nutrient medium.

Reference Medium

The reference medium used for spiking purposes and as a standard against which the different effluents were compared is shown in Table 14 (AAP 1971).

Continuous Culture Assays

Laboratory Tests Continuous culture determinations of biomass under standardized laboratory conditions were determined in accordance with the procedure described in the "Provisional Algal Assay Procedures" (1969). Chemostats were constructed on the basic principles outlined by Middlebrooks et al (1971). Continuously illuminated Cool-white fluorescent lamps were used as the light source. Light intensity, pH, and temperature variations were held within the allowable ranges

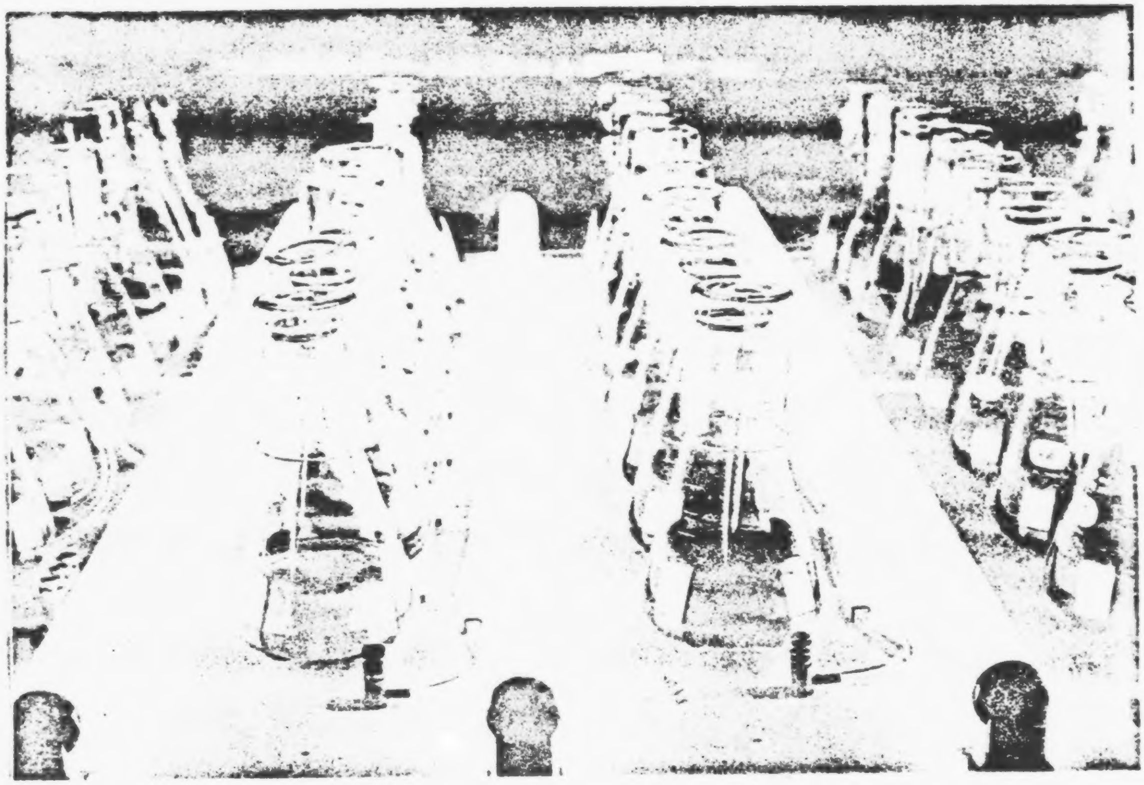

FIGURE 18. BATCH ASSAY UNIT.

specified for batch assays (AAP 1971). A typical continuous culture unit is shown in Figure 19. The composite samples from 21/22 June were used throughout the entire experiment. For purposes of comparison, the standard batch reference medium (AAP 1971) was also used. The Santee samples were stored and used as required while the reference medium was made up in batches from time to time during the course of the experiment. The test alga, Selenastrum capricornutum, was inoculated into chemostats containing one of the Santee effluents or the reference medium at an initial concentration of 10^3 cells per ml. Duplicate chemostats were set up for each effluent and the reference medium. The chemostats were run until a steady state was achieved. (Steady state was defined as less than 10% variation in cell concentration per week.) The chemostats were maintained at a constant

TABLE 14

REFERENCE MEDIUM COMPOSITION

Macronutrients - The following salts, Biological or Reagent grade, in milligrams per liter of glass-distilled water.

Compound	Concentration (mg/ℓ)	Element	Concentration (mg/ℓ)
$NaNO_3$	25.500	N	4.200
K_2HPO_4	1.044	P	0.186
$MgCl_2$	5.700	Mg	2.904
$MgSO_4 \cdot 7H_2O$	14.700	S	1.911
$CaCl_2 \cdot 2H_2O$	4.410	C	2.143
$NaHCO_3$	15.000	Ca	1.202
		Na	11.001
		K	0.469

Micronutrients - The following salts, Biological or Reagent grade, in micrograms per liter of glass-distilled water.

Compound	Concentration (µg/ℓ)	Element	Concentration (µg/ℓ)
H_3BO_3	185.520	B	32.460
$MnCl_2$	264.264	Mn	115.374
$ZnCl_2$	32.709	Zn	15.691
$CoCl_2$	0.780	Co	0.354
$CuCl_2$	0.009	Cu	0.004
$Na_2MoO_4 \cdot 2H_2O$	7.260	Mo	2.878
$FeCl_3$	96.000	Fe	33.051
$Na_2EDTA \cdot 2H_2O$	300.000		

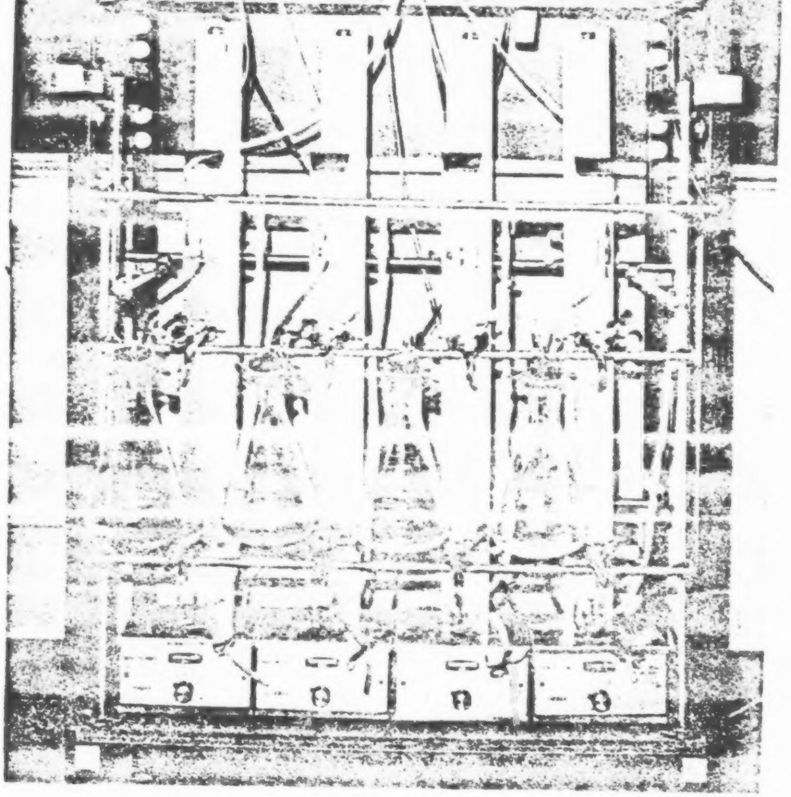

FIGURE 19. CONTINUOUS CULTURE UNIT.

residence time of 10.5 days. This residence time was approximately equal to the hydraulic residence time in the study ponds described below under the field tests.

Field Tests

Field tests were conducted to determine the amount of algal growth in the three process effluents.

Two identical study ponds were constructed adjacent to the tertiary treatment facilities. Each pond was approximately 65 ft x 90 ft and had a depth of 2.6 ft. The flows to the ponds were regulated to maintain a hydraulic residence time of 10 ± 1 days.

The layout of the study ponds is shown on Figure 2 and a typical study pond is shown on Figure 20.

Examination of algal growth during the first phase of the pond monitoring was done with a compound microscope. Quantification was estimated by scanning slides and judging whether the organism was "rare" - "occasional" - "frequent" - or "abundant." Later the number of organisms present were quantified more precisely by using a Nikon inverted microscope model MS. A 5-ml aliquot of the undiluted pond sample was pipetted into a Zeiss counting chamber. One replicate was made. The organisms were settled by adding drops of iodine. Counting was accomplished with Wild oculars containing a millimeter grid ruled 10 squares to a side. Ten strips of 10 squares were counted at random for the 5-ml aliquot and the organisms recorded. The results were expressed in number of organisms per liter. Determinations of total biomass based on dry weight were conducted in accordance with Standard Methods for the Examination of Water and Wastewater, 1965 (14).

A procedure equivalent to that of Secchi-disc determination was used to determine turbidity, although the disc employed was not standard. The measurements were made at mid-day, in sunlight, at the middle of the south sides of the secondary and tertiary ponds.

Determination of Growth Limiting Nutrients

The growth limiting nutrient(s) were determined by means of factorial spiking experiments as described by Murray et al, 1971 (18) and in AAP. "Factor" refers to the element (or combinations of elements added as a single factor) as shown for each experiment. Two sets of spiking experiments were conducted on each type of effluent.

The first spiking experiments were designed to determine the group to which the growth limiting nutrient belonged. The nutrients investigated were classified in the following four groups:

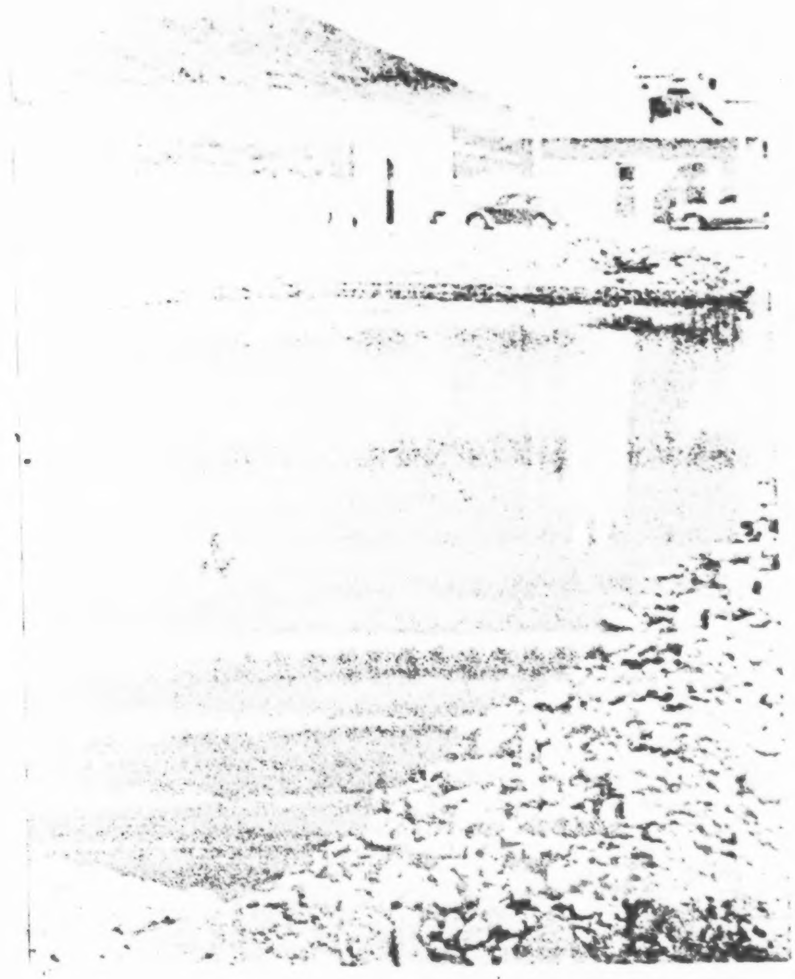

FIGURE 20. TYPICAL STUDY POND.

1. Micronutrients: B, Zn, Co, Cu, Mo
2. Iron and Manganese
3. Phosphorous and Nitrogen
4. Macronutrients: Ca, Mg, Na, K, Cl, S, C

Data from the first spiking experiments were used to select four individual elements which seemed most significant and a second set of factorial experiments designed to select the individual growth limiting nutrient. Elements selected for this set of experiments were:

1. phosphorous
2. iron
3. nitrogen
4. manganese

Spiking Concentrations

Spikings were performed by addition of specified amount of concentrated stock solutions of macro- and micronutrients such that the final spiking after dilution into the effluent being tested correspond to 30 percent of the concentration of the reference medium described above. For example, spiking with iron was done such that 11 ug Fe was added per liter of effluent being tested.

Evaluation Parameters

Three different biomass parameters were used to determine algal growth: cell count, total cell volume and dry weight. The methods used to determine these parameters are described in detail by Murray et al, 1971.

Biomass can be expressed in various ways. Measurement of dry weight is useful in terms of energy values, cell numbers are of significance from a turbidity and analytical point of view, and total cell volume is a useful parameter which may combine the advantages of cell counts and dry weights. Measurements of cell volume correlate best with optical density, what the eye actually sees, and this may be the most useful assessment of algal growth, particularly by the nontechnical viewer.

CHEMICAL ANALYSES

The 21/22 June composite samples and reference medium were analyzed for iron, manganese, nitrite, nitrate and phosphate.

Methods for analysis of nitrites, nitrates, and total phosphorous are those given in FWPCA Methods for Chemical Analysis of Water and Wastes, 1969 (15). The accuracy and precision of the tests are shown in Table 15.

TABLE 15

ACCURACY AND PRECISION OF ANALYTICAL METHODS

COMPOUND	MEAN	COEFFICIENT OF VARIATION (%)[a]
Fe (µg/ℓ)	1	100
	5	20
	31	11
Mn (µg/ℓ)	2	30
	49	31
	135	3
NO_2 (mg/ℓ)	.039	31
	.260	3
	1.14	2
NO_3 (mg/ℓ)	.030	80
	.390	24
	2.15	12
P (mg/ℓ)	.112	21
	.200	22
	3.52	9
	9.76	2

a) coefficient of variation = 100 (standard deviation)/(mean)

Nitrate

This method involves the reaction of nitrate ion with brucine sulfate in 13 N sulfuric acid. Range of method: 0.1 to 2.0 mg/l NO_3-N.

Nitrite

Nitrites form diazonium compound with sulfanilimide. This, coupled with N-(1-napthyl)-ethenediamine forms a reddish color which is read in a spectrophotometer. Range: 0.05 to 1.0 mg/l NO_3-N.

Phosphorous

All the phosphorous in the sample is reduced to orthophosphate by persulfate digestion. An antiomony-phosphate-molybdate complex is then formed and this reacts with ascorbic acid to give a blue color that is proportional to phosphorous content.

Iron and Manganese

Iron and manganese were determined by the method of simultaneous extraction described by Mix and Goodwin, 1970 (22). The metal ions in solution were chelated with diethyldithiocarbamate and extracted with methyl isobutyl ketone prior to determination by atomic absorbtion spectroscopy.

GROWTH LIMITING NUTRIENTS

Determination of the growth-limiting nutrients was a key aspect of the evaluation of the various treatment process effluents. This determination was considered of special significance in this investigation because the various treatment processes do remove different nutrients in unequal proportions. When considering process improvements, it is therefore necessary to know which specific nutrient (or nutrients) are limiting growth of algae.

Each of the treatment effluents as well as the reference medium were evaluated in a two step procedure.

1. The first step was the evaluation of all the nutrients included in the Reference Medium. The nutrients were arranged into four groups (or factors) as discussed in detail under Methods.

2. The second step of the evaluation consisted of a detailed evaluation of the individual nutrients present in those groups which showed a significant effect on growth in the first step above.

The batch assay evaluation in this investigation for the Santee County Water District included only the limiting nutrients as they affect the maximum algal biomass. This choice of approach was based on the specific situation at Santee where all wastes are discharged in lakes having hydraulic residence times in excess of ten days. More comprehensive evaluations including determination of the change in limiting nutrients during the period of growth are reported in "Effect of Nutrient Removal Processes on Algal Growth", 1973 (23). Basing the determination of growth-limiting nutrients on continuous culture experiments was considered. However, because limiting nutrients change as a function of residence/growth time and the need to evaluate and screen many potential limiting nutrients and their interactions, it appeared that factorial multinutrient batch testing would provide a more comprehensive evaluation.

Reference Medium

Growth-limiting nutrients were determined in the reference medium for algal batch bioassays (AAP, 1971) shown in Table 14. The medium was investigated because its exact chemical composition is known and test organisms grow well in it. It should be noted that this medium was very close to tertiary effluent in terms of the amount of biomass produced.

Growth Limiting Nutrients - Reference Medium The results of the determination of groups of growth-limiting nutrients are summarized in Table 16. The corresponding summary results of the evaluation of single nutrients are shown in Table 17.

The groups spiking experiment (Table 16) showed that addition of (Fe + Mn) as a group resulted in an increase in the number of algal cells. The increase amounted to 1.12 10^6 cells per ml or of 23 percent and the increase was statistically significant at the 95 percent level. However, the addition of (Fe + Mn) did not result in a statistically significant increase in either cell volume or dry weight despite the increase in cell numbers.

Both (P + N) and macronutrients limit growth in the reference medium as measured by all three parameters used, cell number, cell volume, and dry weight. Addition of (P + N) shows a greater effect on the final growth than does the addition of macronutrients.

The individual nutrient spiking experiment was based on the results of the group spiking experiment and four individual nutrients were tested. The four nutrients were Fe, Mn, P, N. The results in Table 17 show that of those four nutrients only phosphorous appears to limit growth in the unspiked medium when all three biomass indicators are considered. Spiking with iron results in a slight decrease in final biomass as measured by both cell number and cell volume. This suggests that iron might inhibit growth in the reference medium; however, more work would be necessary prior to determining whether this is a supportable con-

TABLE 16

REFERENCE MEDIUM TESTING OF NUTRIENT GROUPS

EFFECT OF SPIKING

Nutrient Group Spiked	Cell Number (No/mℓ)		Total Cell Volume (mm^3/ℓ)		Dry Weight (mg/ℓ)	
	With (a)	Without (b)	With (a)	Without (b)	With (a)	Without (b)
Trace Metals	5.67×10^6	5.16×10^6	323	293	197	177
Fe + Mn	5.97×10^6	4.85×10^6	322	294	190	184
P + N	6.57×10^6	5.07×10^6	369	247	223	151
Macro-nutrients	5.55×10^6	5.28×10^6	332	284	201	172

SIGNIFICANT FACTORS ON FINAL DAY

Factor	Cell Number	Cell Volume	Dry Weight	Comparison (d)
(Trace)		* (c)		+
(Fe + Mn)	**			+
(P + N)	**	**	**	+
(MACRO)	*	**	*	+

a,b) Each value is the average of one-half of the 32 flasks in the factorial experiment. For example, the value at (a) is the average of the 16 flasks receiving the trace metal spike and the value at (b) is the average of the 16 flasks NOT receiving the trace metal spike.

(c) One star indicates that the addition of the group of nutrients resulted in a change in final biomass which was significant at the 95% level. Two stars indicate a corresponding significance at the 99% level.

(d) A positive comparison indicates that addition of the nutrient group increased the final biomass. A negative comparison indicates a decrease in final biomass when the nutrient group was added.

TABLE 17

REFERENCE MEDIUM TESTING OF INDIVIDUAL NUTRIENTS

Added Single Nutrient	EFFECT OF SPIKING					
	Cell Number (No/mℓ)		Total Cell Volume (mm^3/ℓ)		Dry Weight (mg/ℓ)	
	With (a)	Without (b)	With (a)	Without (b)	With (a)	Without (b)
P	5.33×10^6	3.74×10^6	299	255	136	121
Fe	4.39×10^6	4.67×10^6	265	289	127	130
N	4.50×10^6	4.56×10^6	283	270	130	127
Mn	4.65×10^6	4.42×10^6	287	266	127	130

SIGNIFICANT FACTORS ON FINAL DAY

FACTOR	CELL NUMBER	CELL VOLUME	DRY WEIGHT	COMPARISON
P	**	**	**	+
Fe	*	*		-
N				
Mn		**		+

a,b) Each value is the average of one-half of the 32 flasks in the factorial experiment. For example, the value at (a) is the average of the 16 flasks receiving the trace metal spike and the value at (b) is the average of the 16 flasks NOT receiving the trace metal spike.

(c) One star indicates that the addition of the group of nutrients resulted in a change in final biomass which was significant at the 95% level. Two stars indicate a corresponding significance at the 99% level.

(d) A positive comparison indicates that addition of the nutrient group increased the final biomass. A negative comparison indicates a decrease in final biomass when the nutrient group was added.

clusion.

Secondary Effluent

Secondary effluent samples collected on two different dates were evaluated in the group spiking experiment. The chemical composition of these effluents are shown in Table 18. The results for the first sample (collected on 26 February 1971) are shown in Table 19. The only nutrient group to have a significant effect was (Fe + Mn). The (Fe + Mn) addition resulted in an increased biomass for all three parameters, thus indicating that the growth of algae in that effluent sample was limited by either iron or manganese.

The results for the 21 June 1971 sample are shown in Table 20 also showed an increased biomass as measured by cell number and total cell volume (but not dry weight) with the addition of the (Fe + Mn) groups. However, for this sample of secondary effluent the (P + N) spike resulted in a significant increase for all three parameters of growth. These results indicate that the secondary sample from 21 June has received a different degree of effectiveness in treatment than the sample collected 26 February 1971, resulting in a different N/P ratio.

The individual nutrient spiking was made only on 21 June 1971 sample and results as shown in Table 21 indicate that nitrogen is the limiting nutrient for all three growth parameters. Spiking with the nutrients P and Mn result in decreased biomass for all parameters. The Fe addition has a slight but insignificant increase for cell number and volume on the final day. However, analyses of the detailed results indicated that Fe addition results in increased cell number and volume early in the experiment, i.e. affecting growth rate but not final biomass. The number of samples and the single source of effluent limit the conclusions which can be drawn, it is therefore recommended to expand the investigations to include other secondary effluents and more samples of each effluent.

Tertiary Effluent

Three samples of tertiary effluent were collected under different treatment plant operating conditions and the growth limiting nutrients determined. The sample points and operating conditions are summarized in the introduction to Section VI and the chemical compositions of these effluents are shown in Table 22.

Results of the 26 February sample (Table 23) show that the (P + N) addition results in an increased total cell volume but that the other parameters are not affected significantly. At the same time, the (Fe + Mn) addition results in a decrease in cell numbers. It should be noted that both effects, although statistically significant, are numerically small.

TABLE 18

CHEMICAL COMPOSITION OF SECONDARY EFFLUENTS

Constituent	DATE OF SAMPLING	
	26 Feb 71	21 June 71
Phosphorous mg P/ℓ	11.8	8.85
Nitrate mg N/ℓ	0.9	4.4
Nitrite mg N/ℓ	3.6	0.37
Kjeldahl Nitrogen mg N/ℓ	8.4	14.7
N/P ratio	1.09	2.20
Iron µg/ℓ	No data	1 µg/ℓ ± 1
Manganese µg/ℓ	No data	7 µg/ℓ ± 1

The 21 June sample was taken directly from the lime reactor-clarifier tank because of operating difficulties with the filters in the treatment plant. The sample contained large amounts of flocculated material which appeared to inhibit growth of the test organism. Data from the chemostats described later in the report indicate that batch experiment did not go to completion and that maximum biomass was not attained even after 58 days. Also, there was a significant difference between the replicate flasks for the dry weight parameter. Consequently the results have not been considered in detail.

The results of the group and individual nutrient spiking experiments for the 25 August sample are presented in Tables 24 and 25. Group spiking showed both (Fe + Mn) and (P + N) limiting for all three growth parameters. Spiking with the single nutrients showed that P and Fe were both limiting while N and Mn additions inhibited growth significantly.

TABLE 19

TESTING OF NUTRIENT GROUPS - SECONDARY EFFLUENT - 26 Feb

Nutrient Group Spiked	EFFECT OF SPIKING					
	Cell Number (No/mℓ)		Total Cell Volume (mm³/ℓ)		Dry Weight (mg/ℓ)	
	With (a)	Without (b)	With (a)	Without (b)	With (a)	Without (b)
Trace Metals	3.35×10^7	3.99×10^7	1950	2186	874	909
Fe + Mn	5.43×10^7	1.92×10^7	2518	1618	1091	692
P + N	3.98×10^7	3.38×10^7	2095	2041	904	879
Macro-nutrients	4.08×10^7	3.27×10^7	2141	1995	932	850

SIGNIFICANT FACTORS ON FINAL DAY

Factor	Cell Number	Cell Volume	Dry Weight	Comparison (d)
(Trace)				
(Fe + Mn)	**	**	**	+
(P + N)				
(MACRO)				

a,b) Each value is the average of one-half of the 32 flasks in the factorial experiment. For example, the value at (a) is the average of the 16 flasks receiving the trace metal spike and the value at (b) is the average of the 16 flasks NOT receiving the trace metal spike.

(c) One star indicates that the addition of the group of nutrients resulted in a change in final biomass which was significant at the 95% level. Two stars indicate a corresponding significance at the 99% level.

(d) A positive comparison indicates that addition of the nutrient group increased the final biomass. A negative comparison indicates a decrease in final biomass when the nutrient group was added.

TABLE 20

TESTING OF NUTRIENT GROUPS - SECONDARY EFFLUENT 21-22 June

	EFFECT OF SPIKING					
	Cell Number (No/mℓ)		Total Cell Volume (mm^3/ℓ)		Dry Weight (mg/ℓ)	
Nutrient Group Spiked	With (a)	Without (b)	With (a)	Without (b)	With (a)	Without (b)
Trace Metals	2.30×10^7	2.16×10^7	1326	1246	464	441
Fe + Mn	2.34×10^7	2.11×10^7	1347	1224	474	433
P + N	2.33×10^7	2.10×10^7	1368	1203	467	440
Macro-nutrients	2.08×10^7	2.37×10^7	1239	1332	435	472

SIGNIFICANT FACTORS ON FINAL DAY

Factor	Cell Number	Cell Volume	Dry Weight	Comparison (d)
(Trace)				
(Fe + Mn)	*	**		+
(P + N)	*	**	*	+
(MACRO)	**	*		-

a,b) Each value is the average of one-half of the 32 flasks in the factorial experiment. For example, the value at (a) is the average of the 16 flasks receiving the trace metal spike and the value at (b) is the average of the 16 flasks NOT receiving the trace metal spike.

(c) One star indicates that the addition of the group of nutrients resulted in a change in final biomass which was significant at the 95% level. Two stars indicate a corresponding significance at the 99% level.

(d) A positive comparison indicates that addition of the nutrient group increased the final biomass. A negative comparison indicates a decrease in final biomass when the nutrient group was added.

TABLE 21

TESTING OF INDIVIDUAL NUTRIENTS - SECONDARY EFFLUENT 21-22 June

	EFFECT OF SPIKING					
Added Single Nutrient	Cell Number (No/mℓ)		Total Cell Volume (mm^3/ℓ)		Dry Weight (mg/ℓ)	
	With (a)	Without (b)	With (a)	Without (b)	With (a)	Without (b)
P	1.43×10^7	1.59×10^7	820	913	415	457
Fe	1.53×10^7	1.49×10^7	367	866	432	440
N	1.56×10^7	1.46×10^7	908	825	451	421
Mn	1.37×10^7	1.65×10^7	775	958	377	495

SIGNIFICANT FACTORS ON FINAL DAY

FACTOR	CELL NUMBER	CELL VOLUME	DRY WEIGHT	COMPARISON
P	**	**	**	-
Fe				
N	*	**	*	+
Mn	**	**	**	-

a,b) Each value is the average of one-half of the 32 flasks in the factorial experiment. For example, the value at (a) is the average of the 16 flasks receiving the trace metal spike and the value at (b) is the average of the 16 flasks NOT receiving the trace metal spike.

(c) One star indicates that the addition of the group of nutrients resulted in a change in final biomass which was significant at the 95% level. Two stars indicate a corresponding significance at the 99% level.

(d) A positive comparison indicates that addition of the nutrient group increased the final biomass. A negative comparison indicates a decrease in final biomass when the nutrient group was added.

TABLE 22.

CHEMICAL COMPOSITION OF TERTIARY EFFLUENTS

Constituent	DATE OF SAMPLING 26 Feb 1971	 21 June 1971	 25 Aug 1971
Phosphorous mgP/ℓ	0.77	.280	.21
Nitrate mg N/ℓ	1.10	4.3	
Nitrite mg N/ℓ	0.16	<1.0	<1.0
Kjeldahl Nitrogen mg N/ℓ	4.6	7.82	
N/P ratio	7.61	46.86	
Iron µg/ℓ	No data	<1	<1
Manganese µg/ℓ	No data	1	<1

Electrodialysis Effluent

The chemical composition of the electrodialysis effluent is given in Table 26. Results of the nutrient group spiking experiment are shown in Table 27. The addition of the (Fe + Mn) group resulted in a very significant increase for all three growth parameters while the addition of the macroelement group resulted in a decrease in the final total cell volume and dry weight. This again indicates the potential importance of (Fe + Mn) as growth limiting nutrients.

Results of spiking with the single nutrients are shown in Table 28. Although addition of both Fe and P result in highly significant increases for all biomass parameters, the significance for iron is much greater. The N spike resulted in a significant decrease for all biomass para-

TABLE 23

TESTING OF NUTRIENT GROUPS - TERTIARY EFFLUENT 26 Feb

	EFFECT OF SPIKING					
	Cell Number (No/mℓ)		Total Cell Volume (mm^3/ℓ)		Dry Weight (mg/ℓ)	
Nutrient Group Spiked	With (a)	Without (b)	With (a)	Without (b)	With (a)	Without (b)
Trace Metals	4.37×10^7	4.31×10^7	1975	1956	888	914
Fe + Mn	4.24×10^7	4.44×10^7	1950	1981	915	886
P + N	4.40×10^7	4.28×10^7	1989	1941	891	911
Macro-nutrients	4.26×10^7	4.42×10^7	1946	1985	880	922

SIGNIFICANT FACTORS ON FINAL DAY

Factor	Cell Number	Cell Volume	Dry Weight	Comparison (d)
(Trace)				
(Fe + Mn)	*			-
(P + N)		*		+
(MACRO)				

a,b) Each value is the average of one-half of the 32 flasks in the factorial experiment. For example, the value at (a) is the average of the 16 flasks receiving the trace metal spike and the value at (b) is the average of the 16 flasks NOT receiving the trace metal spike.

(c) One star indicates that the addition of the group of nutrients resulted in a change in final biomass which was significant at the 95% level. Two stars indicate a corresponding significance at the 99% level.

(d) A positive comparison indicates that addition of the nutrient group increased the final biomass. A negative comparison indicates a decrease in final biomass when the nutrient group was added.

TABLE 24

TESTING OF NUTRIENT GROUPS - TERTIARY EFFLUENT 25 Aug

	EFFECT OF SPIKING					
	Cell Number (No/mℓ)		Total Cell Volume (mm^3/ℓ)		Dry Weight (mg/ℓ)	
Nutrient Group Spiked	With (a)	Without (b)	With (a)	Without (b)	With (a)	Without (b)
Trace Metals	3.18×10^6	3.46×10^6	234	266	116	140
Fe + Mn	3.68×10^6	2.95×10^6	283	217	139	117
P + N	3.71×10^6	2.93×10^6	276	224	141	116
Macro-nutrients	3.07×10^6	3.56×10^6	223	277	120	136

SIGNIFICANT FACTORS ON FINAL DAY

Factor	Cell Number	Cell Volume	Dry Weight	Comparison (d)
(Trace)			*	-
(Fe + Mn)	**	**	*	+
(P + N)	**	**	*	+
(MACRO)	**	**		-

a,b) Each value is the average of one-half of the 32 flasks in the factorial experiment. For example, the value at (a) is the average of the 16 flasks receiving the trace metal spike and the value at (b) is the average of the 16 flasks NOT receiving the trace metal spike.

(c) One star indicates that the addition of the group of nutrients resulted in a change in final biomass which was significant at the 95% level. Two stars indicate a corresponding significance at the 99% level.

(d) A positive comparison indicates that addition of the nutrient group increased the final biomass. A negative comparison indicates a decrease in final biomass when the nutrient group was added.

TABLE 25

TESTING OF INDIVIDUAL NUTRIENTS - TERTIARY EFFLUENT 25 AUG.

Added Single Nutrient	EFFECT OF SPIKING					
	Cell Number (No/mℓ)		Total Cell Volume (mm³/ℓ)		Dry Weight (mg/ℓ)	
	With (a)	Without (b)	With (a)	Without (b)	With (a)	Without (b)
P	3.16×10^6	2.75×10^6	224	196	114	95
Fe	3.53×10^6	2.38×10^6	274	146	151	58
N	2.78×10^6	3.14×10^6	193	227	92	116
Mn	2.48×10^6	3.44×10^6	164	256	73	135

SIGNIFICANT FACTORS ON FINAL DAY

FACTOR	CELL NUMBER	CELL VOLUME	DRY WEIGHT	COMPARISON
P	**	**	**	+
Fe	**	**	**	+
N	**	**	**	-
Mn	**	**	**	-

a,b) Each value is the average of one-half of the 32 flasks in the factorial experiment. For example, the value at (a) is the average of the 16 flasks receiving the trace metal spike and the value at (b) is the average of the 16 flasks NOT receiving the trace metal spike.

(c) One star indicates that the addition of the group of nutrients resulted in a change in final biomass which was significant at the 95% level. Two stars indicate a corresponding significance at the 99% level.

(d) A positive comparison indicates that addition of the nutrient group increased the final biomass. A negative comparison indicates a decrease in final biomass when the nutrient group was added.

meters while the Mn caused a decrease in dry weight only. Examinations of the detailed factorial analysis indicated that the numerical effect of the P and N additions are about the same, one increasing growth and the other decreasing growth. Therefore, spiking with the combination of these two nutrients as in the group testing experiments caused no significant effect. This indicates the caution required in interpreting

TABLE 26

CHEMICAL COMPOSITION OF ELECTRODIALYSIS EFFLUENT

Constituent	DATE OF SAMPLING 21 June 1971
Phosphorous mg P/ℓ	.271
Nitrate mg N/ℓ	.390
Nitrite mg N/ℓ	0.27
Kjeldahl Nitrogen mg N/ℓ	0.1[a]
N/P ratio	2.77
Iron µg/ℓ	1
Manganese µg/ℓ	2

[a] estimated value

results both from spiking with groups of nutrients and from evaluation of gross effects of treatment process modifications. In both cases conclusions should be based on overall results plus assessment of growth limiting nutrients. Further, the reason for the negative effects of nitrogen on the algal growth are not clear from the results obtained and further evaluation of Electrodialysis Effluents should be made.

It should be noted that all biomass parameters are higher in individual nutrient spiking experiments. Examination of the detailed results in

TABLE 27

TESTING OF NUTRIENT GROUPS - ELECTRODIALYSIS EFFLUENT 21/22 June

	EFFECT OF SPIKING					
	Cell Number (No/mℓ)		Total Cell Volume (mm³/ℓ)		Dry Weight (mg/ℓ)	
Nutrient Group Spiked	With (a)	Without (b)	With (a)	Without (b)	With (a)	Without (b)
Trace Metals	2.94×10^6	2.52×10^6	140	136	58	60
Fe + Mn	5.07×10^6	3.84×10^6	250	26	105	12
P + N	2.72×10^6	2.74×10^6	138	138	59	58
Macro-nutrients	2.22×10^6	3.24×10^6	103	173	40	77

SIGNIFICANT FACTORS ON FINAL DAY

Factor	Cell Number	Cell Volume	Dry Weight	Comparison (d)
(Trace)				
(Fe + Mn)	**	**	**	+
(P + N)				
(MACRO)		*	*	-

a,b) Each value is the average of one-half of the 32 flasks in the factorial experiment. For example, the value at (a) is the average of the 16 flasks receiving the trace metal spike and the value at (b) is the average of the 16 flasks NOT receiving the trace metal spike.

(c) One star indicates that the addition of the group of nutrients resulted in a change in final biomass which was significant at the 95% level. Two stars indicate a corresponding significance at the 99% level.

(d) A positive comparison indicates that addition of the nutrient group increased the final biomass. A negative comparison indicates a decrease in final biomass when the nutrient group was added.

TABLE 28

TESTING OF INDIVIDUAL NUTRIENTS - ELECTRODIALYSIS EFFLUENT 21/22 June

Added Single Nutrient	EFFECT OF SPIKING					
	Cell Number (No/mℓ)		Total Cell Volume (mm³/ℓ)		Dry Weight (mg/ℓ)	
	With (a)	Without (b)	With (a)	Without (b)	With (a)	Without (b)
P	4.66×10^6	3.73×10^6	260	214	119	88
Fe	5.82×10^6	2.57×10^6	325	150	162	46
N	3.78×10^6	4.61×10^6	220	255	92	116
Mn	4.35×10^6	4.04×10^6	232	242	96	112

SIGNIFICANT FACTORS ON FINAL DAY

FACTOR	CELL NUMBER	CELL VOLUME	DRY WEIGHT	COMPARISON
P	**	**	**	±
Fe	**	**	**	+
N	**	**	**	–
Mn			**	-

a,b) Each value is the average of one-half of the 32 flasks in the factorial experiment. For example, the value at (a) is the average of the 16 flasks receiving the trace metal spike and the value at (b) is the average of the 16 flasks NOT receiving the trace metal spike.

(c) One star indicates that the addition of the group of nutrients resulted in a change in final biomass which was significant at the 95% level. Two stars indicate a corresponding significance at the 99% level.

(d) A positive comparison indicates that addition of the nutrient group increased the final biomass. A negative comparison indicates a decrease in final biomass when the nutrient group was added.

the appendix indicates that this is not caused by spiking alone, as control flasks (Nos. 31 and 32) with nothing added are also much greater (mean cells/ml of 2.5×10^6 vs 4.5×10^5). It appears that the long storage period had considerable effect upon electrodialysis effluent.

Ground Percolated Effluent

Results of nutrient group spiking are shown in Table 29. Addition of the (P + N) group resulted in a highly significant increase in biomass for all growth parameters while the macronutrient addition increased only cell numbers. This data indicates that the (P + N) group is limiting in ground percolated effluent.

Discussion - Batch Algal Assays

The two secondary effluent samples which were evaluated in this work exhibited very different chemical and algal growth characteristics. Characteristic of both samples was the fact that phosphate was not growth limiting (i.e. there was sufficient phosphate present); iron + manganese limited growth in one sample and nitrogen in the other. It should be recognized that the data here are based on only two samples and that broad conclusions cannot be drawn. Nevertheless, both samples were collected as 24 hour composites at a time when the activated sludge plant was performing in a normal manner. Based on these observations, it appears that more investigational work with a broad range of activated sludge effluents should be made.

Of the two good tertiary samples obtained, the one collected 25 August 1971 shows a much lower algal growth than the early sample collected 26 February 1971. These results are in agreement with the overall plant performance during the two periods of operation represented by the two samples. During the last period higher lime dosages were used and this resulted in better phosphate removal as measured by chemical analyses.

The higher lime dosages also resulted in better iron removal, and both iron and phosphate were limiting algal growth with iron being the most significant of the two as indicated by the results in Table 25.

At the same time nitrogen and manganese appeared to be suppressing growth. The reason for this effect is not understood at this time and further work is in progress to verify this finding.

Evaluation of the electrodialysis effluent indicated that iron and phosphate were the growth limiting nutrients and that iron had the most significant effect. This is similar to the results obtained with the tertiary effluent.

The results of the batch assays are summarized on Figure 21, 22, and 23.

TABLE 29

TESTING OF NUTRIENT GROUPS - GROUND PERCOLATED EFFLUENT 26 Feb.

Nutrient Group Spiked	EFFECT OF SPIKING					
	Cell Number (No/mℓ)		Total Cell Volume (mm^3/ℓ)		Dry Weight (mg/ℓ)	
	With (a)	Without (b)	With (a)	Without (b)	With (a)	Without (b)
Trace Metals	3.24×10^6	3.10×10^6	131	135	95	92
Fe + Mn	3.28×10^6	3.05×10^6	134	132	96	90
P + N	4.63×10^6	1.71×10^6	195	71	121	66
Macro-nutrients	3.34×10^6	2.99×10^6	136	130	97	89

SIGNIFICANT FACTORS ON FINAL DAY

Factor	Cell Number	Cell Volume	Dry Weight	Comparison (d)
(Trace)				
(Fe + Mn)				
(P + N)	**	**	**	+
(MACRO)	**			+

a,b) Each value is the average of one-half of the 32 flasks in the factorial experiment. For example, the value at (a) is the average of the 16 flasks receiving the trace metal spike and the value at (b) is the average of the 16 flasks NOT receiving the trace metal spike.

(c) One star indicates that the addition of the group of nutrients resulted in a change in final biomass which was significant at the 95% level. Two stars indicate a corresponding significance at the 99% level.

(d) A positive comparison indicates that addition of the nutrient group increased the final biomass. A negative comparison indicates a decrease in final biomass when the nutrient group was added.

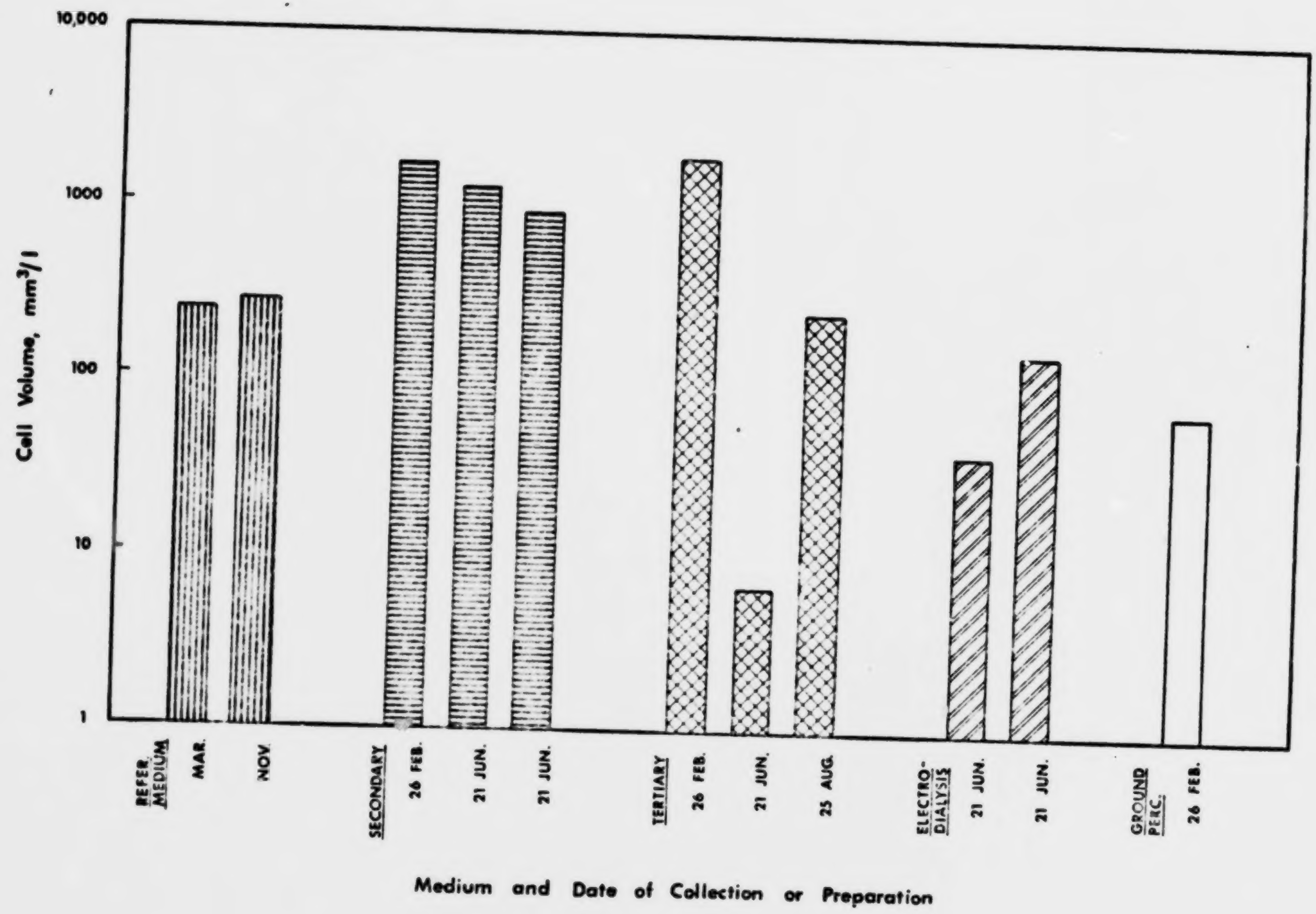

FIGURE 21. FINAL CELL VOLUME IN CONTROL FLASKS OF VARIOUS MEDIA

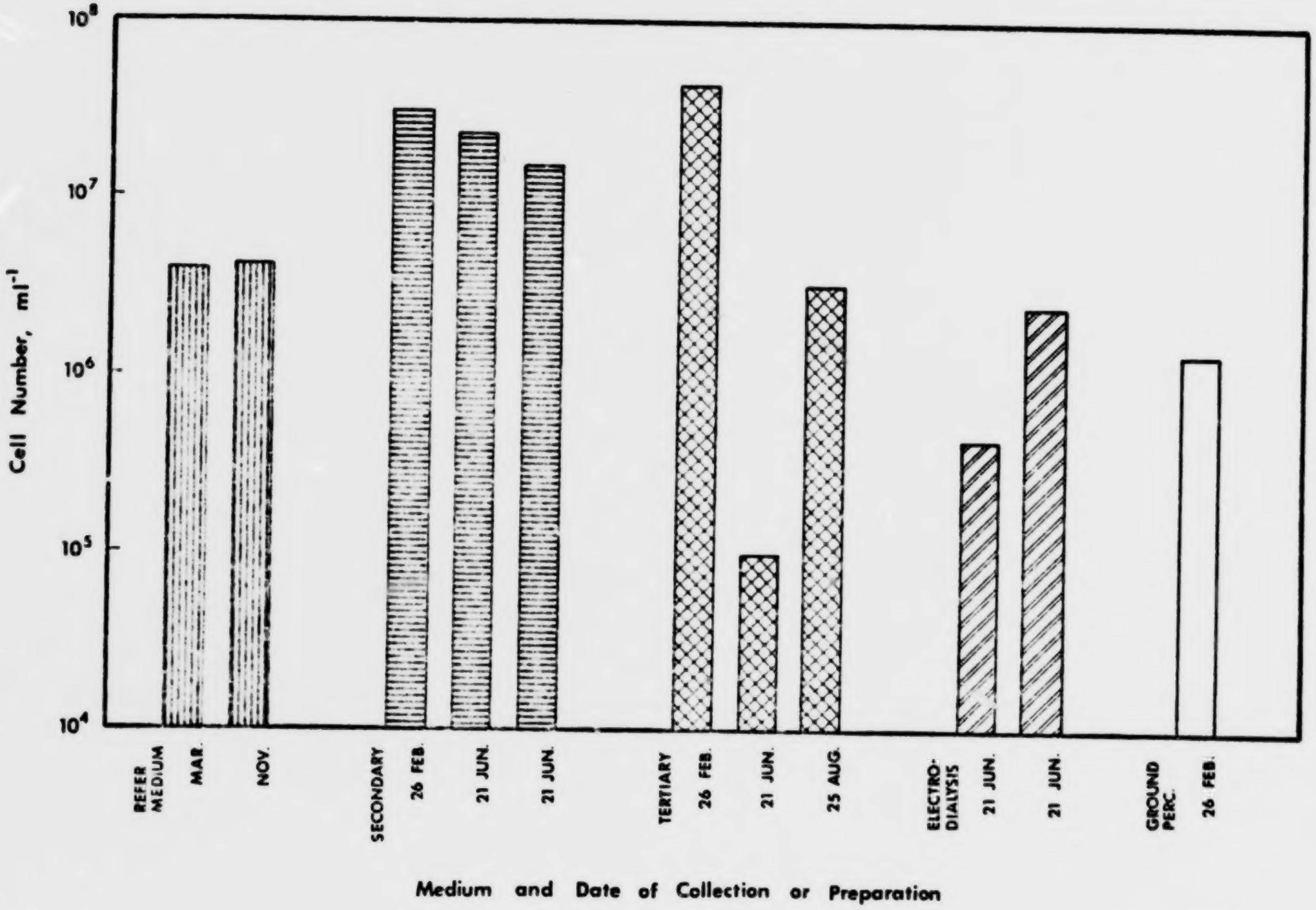

FIGURE 22. FINAL CELL NUMBER IN CONTROL FLASKS OF VARIOUS MEDIA

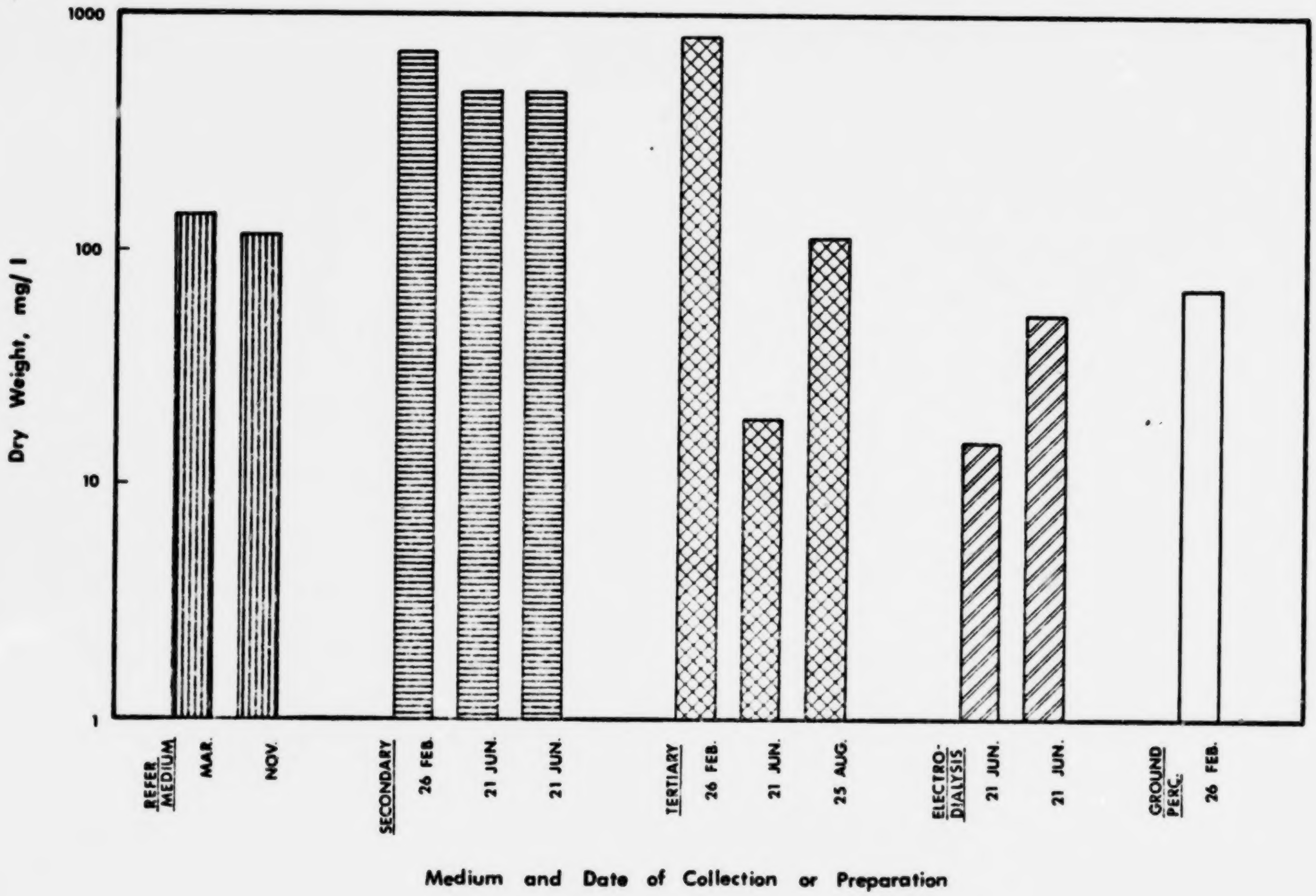

FIGURE 23. FINAL DRY WEIGHT IN CONTROL FLASKS OF VARIOUS MEDIA

The results are in general agreement with those obtained with the continuous culture units and signify to the relative improvement in effluent characteristics resulting from the tertiary treatment processes investigated at Santee.

CONTINUOUS CULTURE INVESTIGATIONS

Laboratory Investigations

Introduction

In order to evaluate a waste management program, or the quality of the different effluents from such a program, a procedure which will provide data on different levels of algal growth at steady state may serve as a useful management tool. A continuous-flow laboratory culture can serve as such a tool because it simulates growth likely to occur in a body of water receiving a given effluent.

In the research described here, one liter chemostates were used (PAAP, 1969 (17), Maloney, 1971 (20), Middlebrooks et. al., 1971 (19), and the results compared with the algal growths which occurred in the field in test ponds receiving the same effluents. With a residence time of 10.5 days, the laboratory chemostats required 99 days to reach steady state. This is a surprising length of time, in view of the consistency of the media and the conditions of culture. Steady state conditions were maintained for the recommended two residence times or 21 days. Measurement of cell number, mass and volume were performed on the effluents from the four chemostats on four or five occasions during this 21 day period.

The biomass expressed as dry weight (mg/1), for each of the three types of Santee effluent and the standard algal growth medium are shown in Figure 24. The results show:

1. The variation in biomass was relatively significant over a 21 day period and that steady state conditions, has, in fact, been achieved and maintained; and
2. The growth of the three effluents and the reference medium could be ranked in the following decending order, Secondary > Tertiary > NAAM > Electrodialysis.

Biomass can be expressed in various ways. Measurement of dry weight is useful in terms of energy values although in terms of practical application cell number and cell volumes may be the most useful parameters. Measurements of cell volume correlate best with optical density, what the eye actually sees, and this is the most likely assessment of algal growth, particularly by the nontechnical viewer. Average values for dry weight, (expressed as mg/1), cell number (expressed as number/1) and cell volume (expressed as $mm^3/1$) are given in Table 30.

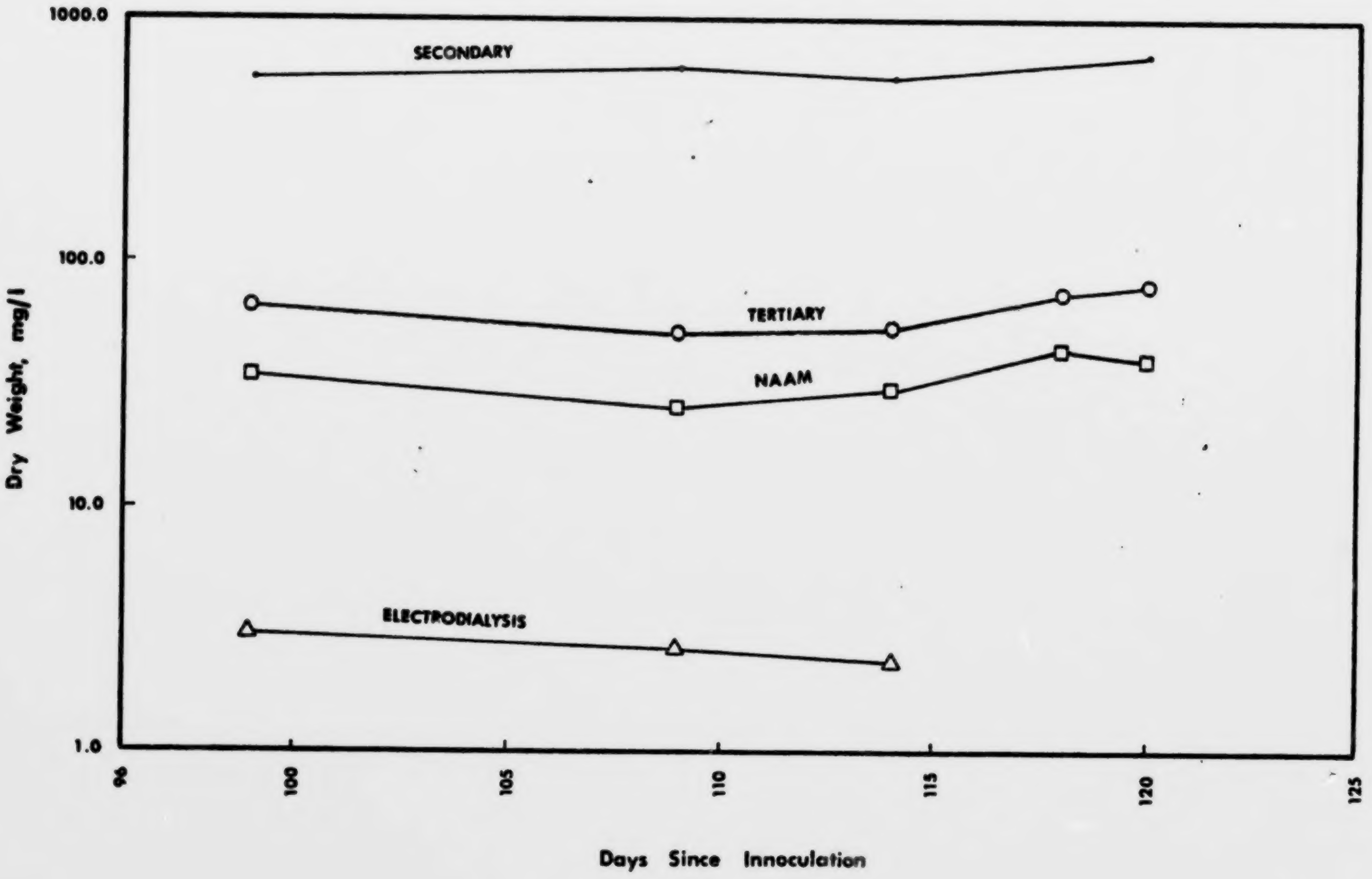

FIGURE 24. DRY WEIGHT IN CONTINUOUS FLOW CULTURES DURING STEADY STATE

TABLE 30

STEADY STATE BIOMASS CONCENTRATIONS IN CONTINUOUS CULTURES AT 10.5 DAYS·RESIDENCE TIME

Biomass of chemostate continuous cultures of Santee secondary effluent, electrodialysis effluent, and reference medium expressed in terms of dry weight, cell number and total cell volume, using *Selanastrum capricornutum* as the test organism. These figures are mean values for the two chemostats estaolished for each effluent and the reference medium.

Effluent or culture medium [a)	Dry Weight (mg/ℓ)	Cell Number per mℓ	Total cell volume (mm^3/ℓ)
Santee secondary effluent	580	144×10^5	1222
Santee tertiary effluent	63	7.50×10^5	110
Santee electrodialysis effluent	2.7	0.192×10^5	1.53
Reference medium	35.5	3.5×10^5	42

a) All samples collected 21 June 1971.

In every case, the three effluents can be ranked in the descending sequence secondary effluent > tertiary effluent > electrodialysis effluent. The values obtained with the reference medium place it between tertiary effluent and electrodialysis effluent, with values approximately half those for the tertiary effluent in every feature measured. The results are expressed graphically in Figure 25.

The major problems involved in these chemostat experiments were a consequence of flocculant material present, particularly in the tertiary effluent. The material appeared to be organic with possible nutrients chelated onto them. Filtration would have removed these nutrients so that they had to be retained in the chemostats despite the difficulties involved in using a Coulter Counter on fluids containing such flocculant material. It might well have been that the long

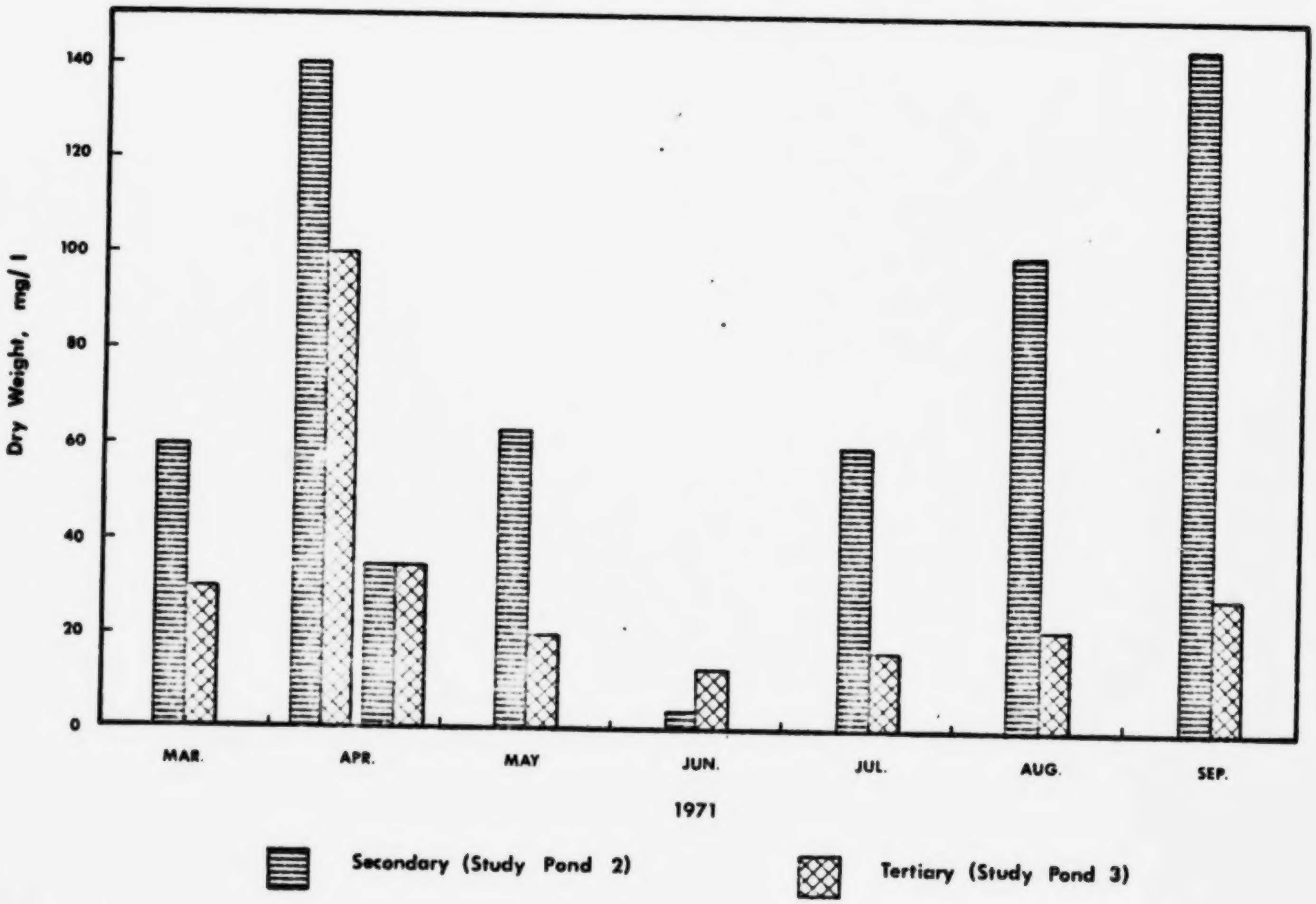

FIGURE 25. BIOMASS PRESENT IN STUDY PONDS

time required for stability was consequence of slow equilibration with these chelated nutrients. Examination of the algae in the chemostats at the end of the experiment showed that after a period of nearly four months, the levels of contamination were not excessive. Bacterial growth was present in all the effluents and the reference medium, with the highest levels in the tertiary effluent. A small quantity of blue-green algal contaminant was also present in the chemostats with tertiary effluent.

Field Investigations

Application of the chemostat, continuous culture concept to lakes of much greater volume than a laboratory chemostat tube provide a transition to those natural situations were effluents of different types are discharged into natural bodies of water. In this way natural populations of many algal species may be evaluated under realistic field conditions. The algal flora in a pond receiving a specifically treated and presumably well defined effluent might be expected to display uniform behavior, particularly in an area such as Santee, California, where atmospheric variables are as stable and predictable as any to be found. Furthermore, the flora of ponds receiving effluents from different treatments might be expected to show certain specific differences.

Two study ponds were established in the location between the treatment plant and the lakes. The operating parameters for the two ponds were as follows:

POND NO.	SOURCE	VOLUME (gal.)	DEPTH (ft.)	FLOW (gal/min)	RESIDENCE TIME (days)
1	Secondary effluent	116,000	2.5	10	8.02
2	Tertiary effluent	124,000	2.6	10	8.62

The objectives of the field assay investigations were to determine:

1. The total biomass which will develop in continuous culture, under field conditions, in the different types of effluent.
2. The species composition of the biomass in the effluents of different type.
3. The relative amounts of growth in the two ponds.
4. The comparison between absolute and relative amounts of growth under field conditions with the corresponding results determined in the laboratory continuous cultures.

Preliminary samples were obtained from the study ponds during the spring and early summer months (1971) in order to become familiar with algal floras. Samples were collected, generally in the late morning, from the midpoint on the shore on each side of each pond by means of a plastic container on a long rod. These four sub-samples were then combined and examined microscopically in order to determine the organisms present.

The organisms survey were limited to those suspended in the water because filamentous material did not develop except on a few stones near the inflow pipe. This was fortunate, in that assessment of the biomass of epiphytic and epilithic periphyton is notoriously difficult to undertake in any meaningful manner.

Examination during the preliminary phase of monitoring the pond flora was done with a compound microscope. Quantification was estimated by scanning slides and judging whether the organism was "rare" - "occasional" - "frequent" or "abundant." During the later part of the investigation, the number of organisms present were quantified more precisely by using a Nikon inverted microscope, Model MS. A 5-ml aliquot of the undiluted pond sample was pipetted into a Zeiss counting chamber and a second replicate made. The organisms were settled by adding drops of iodine. Counting was accomplished with Wild oculars containing a millimeter grid ruled 10 squares to a side. Ten strips of 10 squares were counted at random for the 5-ml aliquot and the organisms recorded. The results were expressed in numbers of organisms per liter. Determinations of total biomass based on dry weight measurements were conducted in accordance with Standard Methods. Estimates of color were made visually.

For measurement of turbidity a procedure equivalent to that of Secchi-disc determination was used although the disc employed was not standard. This was placed in the ponds and the depths at which it disappeared noted. The measurements were made at mid-day, in sunlight, at the middle of the south sides of the secondary and tertiary ponds.

Results

1. Estimates of total biomass in the ponds receiving secondary and tertiary effluents.
   The algal biomass, expressed in terms of mg per liter, present in the ponds receiving secondary and tertiary effluents, during the period of investigation are shown in Table 31 and these results are plotted in Figure 25.
2. Determinations of biomass by Secchi-disc measurements.
   The depths at which the home-made Secchi-disc vanished are indicated in Table 32.
3. Identification of species and relative abundance.
   Summaries of the major algal species in the ponds receiving secondary and tertiary effluents are given in Tables 33 and 34.

TABLE 31

Biomass expressed in mg/ℓ present in ponds receiving secondary and tertiary effluents

DATE	POND 2 Secondary effluent	POND 3 Tertiary effluent
19 Mar '71	60	30
1 Apr '71	142	104
15 Apr '71	36	36
19 May '71	62	20
21 June '71	2	12
22 July '71	63	17
25 Aug '71	109	21
23 Sept.'71	139	28
AVERAGE	77	33
STANDARD DEVIATIONS	46	28

Discussion

1. Algal biomass in ponds receiving secondary and tertiary effluents.

Considering the algal blooms present in the ponds receiving secondary and tertiary effluent, the values for the tertiary pond were (with one exception) lower than the values for secondary pond. Concurrent factors which varied significantly between the two ponds and might be influencing or reflecting these differences include:

1. Total phosphate was about 2 mg/1 greater in the secondary pond that the tertiary.
2. Orthophosphate of the filtrate was also about 2 mg/1 greater.
3. Alkalinity of the secondary was about 100 mg/1 greater that the tertiary.
4. Ammonia filtrate of the secondary effluent was about 1.5 mg/1 greater than the tertiary.
5. Suspended solids were about 35 mg/1 greater than the tertiary.

TABLE 32

Depths at which Secchi-disk disappeared in ponds receiving secondary and tertiary effluent.

DATE	POND 2 (secondary)	POND 3 (tertiary)	% better clarity POND 2	% better clarity POND 3
5 Aug.'71	10 inches	22.5 inches		125%
20 Aug.'71	11.5 "	14 "		21.7%
27 Aug.'71	18 "	15 "	20%	
14 Sep.'71	15 "	36 "		140%
AVERAGE	13.6 inches	21.9 inches		61%

6. Chemical oxygen demand of secondary effluent was about 30 mg/l greater than that of the tertiary effluent, and
7. COD filtrate was about 20 mg/l greater than the tertiary.

At the same time -

1. pH of the two was about equal.
2. Dissolved oxygen was about equal; and
3. nitrate filtrate was equal.

However, nitrate filtrate of the secondary pond was slightly lower than the tertiary. The temperature during the entire study period climbed steadily from a minimum in February 1971 of 16°C to a maximum of about 25°C in August. Although the quality of tertiary effluent, as reflected in algal pond growth, had made a good recovery by mid-August, the secondary effluent did not show this rapid recovery and was continuing to deteriorate, in terms of the quantity of algal growth, as the project was terminated.

TABLE 33

COLOR OBSERVATIONS AND MAJOR ALGAL COMPONENTS - SECONDARY POND #2

DATE 1971	COLOR	ORGANISMS (abundant or 10^6)	ORGANISMS (frequent or 10^7,
26 Feb.	None recorded	naviculoid diatom	Cryptomonas Pedinomonas Sphaerellepsis (?) 6-micron flagellate
19 Mar	None recorded	Euglena (naviculoid diatom abundant on rocks)	
1 Apr	Lower end darker; color not specified	Chlamydomonas Cryptomonas Eutroptia (?)	Euglena Scendesmus acuminatus Oscillatoria
15 Apr	Yellowish-green	None taken	None taken
19 May	Yellow-green	Chlamydomonas	Chlorogonium Oscillatoria
21 June	None recorded	Oscillatoria, $1.8 \times 10^8/\ell$ coccoid blue-green $3.78 \times 10^8/\ell$	(Others, 10^6)
22 July	None recorded	coccoid green, $1.12 \times 10^8/\ell$ coccoid blue-green $4.20 \times 10^8/\ell$ Chlorogonium, $2.27 \times 10^8/\ell$	Scenedesmus acuminatur, 2.25×10^7 Merismopedia, cells $4.28 \times 10^7/\ell$ flagellate, $1.87 \times 10^7/\ell$ Pedinomonas, $1.75 \times 10^7/\ell$
25 Aug	Dark grassy green	Chlorogonium, $3.68 \times 10^8/\ell$ coccoid blue-green, $4.20 \times 10^8/\ell$	coccoid green, $2.67 \times 10^7/\ell$ Merismopedia, cells $4.28 \times 10^7/\ell$
23 Sept	Dark grassy green	Actinastrum, $1.08 \times 10^8/\ell$ coccoid blue-green, $3.28 \times 10^8/\ell$ Chlorogonium, $2.56 \times 10^8/\ell$ Chlamydomonas, 2.73 c $10^8/\ell$	coccoid green, $3.13 \times 10^7/\ell$ Oscillatoria, $1.25 \times 10^7/\ell$

TABLE 34

COLOR OBSERVATIONS AND MAJOR ALGAL COMPONENTS - TERTIARY POND #3

DATE 1971	COLOR	ORGANISMS (abundant or 10^8)	ORGANISMS (frequent or 10^7)
26 Feb	None recorded	coccoid green Chlaydomonas	Chlorococcum (?) Euglena naviculoid diatom
19 Mar	None recorded	(2 flagellates and 2 green algae in 'occasional' amount)	12-micron flagellate
1 Apr	Lower end darker; color not specified	2-micron flagellate	3-micron coccoid green 5-micron coccoid green Chlaymydomonas
19 May	Brownish-green	(none abundant, others 'occasional to rare')	Ankistrodesmus Oscillatoria
21 June	None specified	coccoid-blue-green, $1.6 \times 10^9/\ell$ Oscillatoria, $2.58 \times 10^8/\ell$	Scenedesmus quadricauda, 1.0×10^7 Chlamydomonas, $1.0 \times 10^7/\ell$ chrysophyte flagellate,
22 July	None specified	(10^6 only)	coccoid green, $1.9 \times 10^7/\ell$ small green flagellate, $0.9 \times 10^7/\ell$ coccoid blue-green, $4.6 \times 10^7/\ell$
25 Aug	Bluish - to light green	coccoid blue-green, $5.57 \times 10^9/\ell$	(others 10^6)
23 Sept	Bluish-green	Actinastrum, $2.0 \times 10^8/\ell$ Pediastrum, $2.8 \times 10^8/\ell$	coccoid green, $5.50 \times 10^7/\ell$ Chlamydomonas, $1.0 \times 10^7/\ell$ coccoid blue-green, $7.25 \times 10^7/\ell$ Merismopedia, cells $2.5 \times 10^7/\ell$

Clarity of the pond waters was measured with the Secchi-disc. The technique appears to be a simple method, highly suitable for assessing the amount of algal growth which is supported by the effluents in each of the study ponds. The major disadvantage is that particulate matter, which might be present, also influences the readings. This is particularly critical in any circumstances in which secondary effluent is likely to be used. The disc procedure measures total turbidity, i.e. of both particulate and biological origin, and the figures obtained correlate well with turbidity measurements taken at the ponds by the plant personnel. (Appendix D) Differences in disc measurements between secondary and tertiary effluents, as they occur in the ponds, are generally quite marked, with the tertiary pond registering greater clarity with one exception. Overall the tertiary pond averaged 61% greater clarity over the period of these measurements, taken during the hottest time of the year.

It is interesting to note that the tertiary pond, at the time when disc measurements were less than those of the secondary (27 August), was experiencing an abnormally high bloom of a coccoid blue-green alga. The bloom caused the pond to appear uniformly bluish-to light green. The pH at that time was on the decline to the point where it had just fallen below that of the secondary pond. Total phosphate and alkalinity were also low.

2. Floristic analysis of the algal growths in ponds receiving secondary and tertiary effluents.

The algal flora in a pond receiving a specifically treated and presumably well defined effluent might be expected to display uniform algal growth, particularly in a region such as Santee where climatic fluctuation is relatively limited. Unfortunately it was not possible to demonstrate evidence in support of this expectation as indicated by the summary of predominant species in Tables 33 and 34. The floristic changes, are in terms of species composition and quantity, are as dramatic as any which have been found in any natural situation of an undefined nature (Talling, 1951).

Although the study ponds did not support permanent populations of ducks or other waterfowl, transient visitors could be expected in almost any outside pond. Early morning surveys would be needed to confirm this. At Santee, bullfrogs were always apparent and more than once a large bittern was flushed from a small cluster of cattails which grew in the corner of one pond. By comparison with the nutrient status of the pond water, the enrichment contribution from these animals was undoubtedly negligible, but they act as a source of inoculation of the pond with new algal components carried by feet or feathers and in the alimentary tract. Atmospheric transportation of all manner of spores, cysts, and propagules can be expected. Although it had been anticipated, with the sources of water available, that the flora of the ponds would be relatively uniform, this was not the case. The composition of the algal flora was as varied and completely unrelated between ponds as is usually the case with freshwater environments.

An effort was made to relate the color of the water in the different ponds with the species composition. These data are included in Tables 33 and 34. In general the secondary study pond consistently appeared more intensely green and more murky or turbid than the tertiary pond.

Color in the secondary pond varied from yellowish-green to dark grassy green. The most abundant organism, when yellow-green was noted, was Chlamydomonas, while another green flagellate (Chlorogonium), considerably larger than Chlamydomonas, was present in large numbers. However, the second flagellate was equalled in numbers by a blue-green filament which, by sheer size and pigmentation differences, apparently did not contribute much to pond hue. The presence of blue-green algae in less than bloom quantity is not easily detected. The figures can be misleading until the exceedingly small size of most blue-green algae is considered in comparison to the larger green flagellates, such as Chlorogonium. When two green and two blue-green organisms were present in almost equal numbers, the secondary pond appeared dark grassy green. It is interesting that on the same day (25 August) the tertiary pond a few feet away contained an excessive amount of tiny coccoid blue-green alga and appeared bluish to light green. Color is, therefore, not too reliable a visual index of the constituents of the population supported by the pond. A correlation appears between turbidity and dry weight samples. It is suggested that Secchi-disc measurements be taken as a rapid, simple indication of standing crop. Unfortunately this was not appreciated until it was too late for meaningful incorporation in the present study. It is also suggested that water samples be taken more frequently, preferably weekly, in order to monitor more precisely the changes in biotic composition.

3. Correlation between Chemical Parameters and Algal Biomass.

Correlation by visual consideration of the data failed to disclose any obvious relationship between the amount and kinds of organisms present and the chemical analyses of the study ponds (Appendix D).

An attempt was therefore made to relate the various chemical and physical parameters with the algal biomass over a series of periods throughout the duration of testing. A correlation coefficient was calculated for both secondary and tertiary effluents relating the algal biomass at the end of the test periods with the average values for each chemical and physical parameter during the period. The correlation coefficients are presented in Tables 35 and 36. The highest correlation coefficient with secondary effluent occurred with alkalinity and that was merely 0.52; no other value exceeded 0.50. For tertiary effluent, the correlation coefficients were slightly

TABLE 35 Correlation, over 8 test periods, between the biomass on the last day of each period and the average values for various chemical and physical parameters for each period, in ponds receiving Santee secondary effluent.

Periods, indicated in days of the year	51-78	78-91	91-105	105-139	139-172	172-203	203-237	237-266	CORRELATION COEFFICIENT
Biomass, on last day of period (in mg/ℓ)	60	142	36	62	2	63	109	139	-
Total Phosphate	11.4	10.8	12.2	11.9	13.3	15.1	14.7	10.5†	.37
Orthophosphate	10.6	10.3	11.1	10.7	10.0	12.3	13.4	10.5†	.16
Alkalinity	175	148	120	149*	139	175	260	202	.52
Ammonium filtrate	4.2	2.5	4.0*	1.73†	1.32	3.38			.12
Suspended solids	33	37	46	42	41*	51	44*	37†	.32
COD	54.8	51.6	55.0	63.9*	45.8	54.3	53.5	64.4†	.42
COD filtrate	44.9	39.1	37.3	45.5	34.8	38.7			.30
pH	7.4	7.3	7.3	7.3	7.[illegible]*	7.4	7.1	7.3	.50
Nitrite filtrate	2.50	0.94	0.52	0.56*	0.48	0.54			.19
Nitrate filtrate	1.4	1.8	1.7	1.4	1.4	1.1			.42
Turbidity, Avg.	6.5	6.8*	8.3	10.9	7.3*	9.5	7.5	9.0	.05
Last day turbidity	4.0	8.5	13.0	7.0	7.0	10.0	9.0	14.0	.32
Number of points[1]	8	3	4	8	9	8	6	21	

[1] Number of points indicates number of days data taken in each period
* Number of data points less than indicated for particular period
† Outlier excluded from data

TABLE 36 Correlation, over 7 test periods, between the biomass on the last day of each period and the average values for various chemical and physical parameters for each period, in ponds receiving Santee tertiary effluent.

Period, Indicated In days of the year	51-78	78-91	91-105	105-139	139-172	172-203	203-237	237-266	CORRELATION COEFFICIENT
Biomass, on last day of period (in mg/ℓ)	30	104	36	20	12	17	21	28	-
Total Phosphate	1.4	1.6*	1.8*	2.0*	1.0*	0.6		0.2*	.30
Orthophosphate	1.3*	1.7*	1.8*	1.9*	0.9*	0.3		0.1*	.40
Alkalinity	214	209	160	198*	155*	128			.52
Ammonium filtrate	3.6	1.6*	3.8*	1.4*	2.7*	4.1			.44
Suspended solids	17*	22*	27	24*	32*	27			.39
COD	34.6	32.1	29.4	29.5*	23.0	24.7			.53
COD filtrate	30.2	29.8*	29.0*	27.6*	21.1*				.53
pH	7.8	7.8	7.9	7.8	8.2	8.2			.52
Nitrite filtrate	0.15	0.38*	0.38*	0.23*	0.28*	0.26			.57
Nitrate filtrate	1.5	1.9*	1.4*	1.5*	1.4*	1.2*			.89
Turbidity, Avg.	3.4	2.1†	2.5	2.8	2.8	2.8			.70
Last day turbidity	2.0	1.0	3.3	1.5	2.5	3.0			.61
Number of points[1]	14	7	8	17	18	12			

[1] Number of points indicates number of days data taken in each period

* Number of data points less than indicated for particular period

† Outlier excluded from data

higher, but even so were not of any great significance. The highest value occurred for the correlation between nitrate filtrate and biomass and that was only .89. These data indicate that there is no acceptable correlation between the biomass and any chemical parameter for the two effluents when considered individually. However, the comparison between the growth in the two ponds substantiates the laboratory results.

SECTION VII

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SECTION VIII

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SECTION IX

GLOSSARY

(The author believes this section is unnecessary.)

SECTION X

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APPENDIX A

TABLE A-1. AVERAGE DAILY FLOW AND LIME DOSE

Day	Flow M.G.D.	Lime Dose mg/l
1970		
316-317	.97	200
317-320	1.24	237
320-322	1.29	178
322-323	1.68	145
323-324	1.59	165
324-327	1.24	425
327-328	1.55	155
328-329	1.11	156
329-330	1.95	225
330-331	1.93	176
331-334	1.88	146
334-335	1.86	136
335-336	1.85	174
336-337	1.86	118
337-338	1.74	129
338-341	1.88	151
341-342	1.91	169
342-343	1.90	214
343-344	1.88	250
344-345	1.88	236
345-348	1.87	243
348-349	1.56	228
349-350	1.98	182
350-351	1.94	129
351-352	1.94	179
352-355	1.94	165
355-356	1.94	87
356-357	1.79	160
357-258	1.94	181
358-363	1.96	181
363-4	1.18	162
1971		
4-5	1.66	179
5-6	1.04	165
6-7	1.08	169
7-8	1.04	215
8-11	1.00	129
11-12	.68	177
12-13	.97	97
13-14	.85	115
1971		
14-15	.87	118
15-18	.86	129
18-19	1.14	171
19-20	1.47	162
20-21	1.79	146
21-22	1.64	128
22-27	1.61	175
27-28	1.63	178
28-29	1.63	167
29-32	---	---
32-33	1.80	146
33-34	1.72	142
34-35	1.42	140
35-36	1.84	130
36-39	1.72	118
39-40	1.47	120
40-42	1.49	138
42-47	1.89	120
47-48	1.73	134
48-49	1.02	156
49-50	.99	181
50-53	.99	159
53-54	1.10	160
54-55	1.12	148
55-56	1.28	140
56-57	1.38	138
57-60	1.48	90
60-61	1.68	86
61-62	1.65	85
62-63	1.90	76
63-64	1.87	83
64-67	1.75	68
67-68	1.74	89
68-69	1.93	56
69-70	1.78	63
70-71	1.79	69
71-74	1.64	73
74-75	1.56	87
75-76	1.88	88
76-77	1.96	63
77-78	1.93	63

TABLE A-1. AVERAGE DAILY FLOW AND LIME DOSE (continued)

Day	Flow M.G.D.	Lime Dose mg/l
1971		
78-81	1.91	65
81-82	1.96	68
82-83	2.04	56
83-84	2.02	53
84-85	1.96	54
85-88	1.70	58
88-89	1.97	84
89-90	1.90	83
90-91	1.52	61
91-92	1.69	67
92-95	1.48	60
95-96	1.62	33
96-97	1.45	50
97-98	1.14	47
98-99	1.41	43
99-102	1.47	43
102-103	1.79	51
103-104	1.94	46
104-105	1.94	56
105-106	1.99	45
106-109	1.41	50
109-110	1.67	38
110-111	1.81	48
111-112	1.88	52
112-116	---	---
116-117	1.90	56
117-118	1.51	69
118-119	1.64	61
119-120	1.93	68
120-123	1.62	58
123-124	1.74	57
124-125	1.00	65
125-126	1.40	58
126-127	1.61	46
127-130	1.76	45
130-131	1.86	45
131-132	1.87	44
132-133	2.00	47
133-141	1.60	55
141-144	1.19	100
144-145	.95	48

Day	Flow M.G.D.	Lime Dose mg/l
1971		
145-146	.88	55
146-147	.90	86
147-148	1.15	131
148-152	.77	154
152-153	.73	99
153-154	.76	110
154-155	.74	216
155-158	1.02	123
158-159	.89	216
159-160	.79	204
160-161	.80	201
161-162	.68	245
162-165	.86	187
165-166	1.02	188
166-167	1.03	194
167-168	1.14	150
168-169	1.22	194
169-172	1.12	172
172-173	.85	207
173-174	1.30	212
174-175	1.22	227
175-176	1.17	222
176-179	1.06	215
179-180	1.17	234
180-181	1.12	221
181-182	1.32	169
182-183	1.32	164
183-187	1.27	188
187-188	1.23	216
188-189	1.26	213
189-190	1.26	235
190-193	1.08	265
193-194	1.11	249
194-195	1.16	171
195-196	1.14	174
196-197	1.19	169
197-200	1.15	173
200-208	---	---
208-209	.71	---
209-210	.64	---
210-211	1.20	170

TABLE A-1 AVERAGE DAILY FLOW AND LIME DOSE (continued)

Day	Flow M.G.D.	Lime Dose mg/1
1971		
211-214	1.24	171
214-215	1.20	193
215-216	1.20	192
216-217	1.21	191
217-218	1.19	195
218-221	.78	207
221-222	1.18	198
222-223	1.21	194
223-224	1.20	192
224-225	1.22	194
225-229	---	---
229-230	1.19	203
230-231	1.22	200
231-232	1.23	178
232-235	.91	181
235-236	1.10	220
236-237	1.12	216
237-238	1.19	207
238-239	1.18	210
239-242	.90	192
242-243	1.16	203

Day	Flow M.G.D.	Lime Dose mg/1
1971		
243-244	1.08	232
244-245	1.14	219
245-246	1.09	229
246-250	.75	235
250-251	1.16	216
251-252	1.15	217
252-253	1.16	218
253-256	.80	189
256-257	1.12	203
257-258	1.09	231
258-259	1.09	227
259-260	1.12	222
260-263	.81	306
263-264	1.11	212
264-265	1.02	238
265-266	1.14	216
266-267	.97	210
267-270	.65	184
270-271	1.11	214
271-272	1.17	206
272-273	1.05	230

APPENDIX B

TABLE B-1 REACTOR-CLARIFIER INFLUENT, COMPOSITE SAMPLES, PART 1

24 hour composite samples, results in mg/l.

Day	Total Phosphorus as P	Ortho Phosphate Filtrate as P	Total Kjeldahl as N	Ammonia Filtrate as N	Nitrite Filtrate as N	Nitrate Filtrate as N
1970						
145-146	16.34	14.05	9.12	2.36	0.35	5.5
147-148	15.0	14.0				
154-155	14.05	13.1				
159-160	15.0	13.07	6.08	1.39	0.20	0.90
166-167	15.03	13.07	8.21	7.15	0.40	0.65
168-169	16.34	14.71				
173-174	21.9	16.3	23.1	6.6	0.15	4.5
175-176	17.32	14.05		0.58	1.80	13.0
180-181	18.3	16.3	9.73	8.97	3.05	11.0
182-183	16.3	13.7		2.50	5.0	13.0
187-188	18.6	15.0	9.00	2.82	2.3	10.0
189-190	17.3	15.0		1.98	2.5	11.5
195-196	14.05	11.57	7.6	1.90	2.70	3.6
197-198	16.3	11.4		1.98	5.5	2.8
202-203	13.07	13.07	5.78	1.82	1.9	1.9
204-205	15.0	12.4		4.79	0.9	20.0
209-210	15.0	13.7	7.3	0.86	0.70	3.4
211-212	14.4	13.7		1.13	0.35	4.0
215-217	17.6	16.3	2.74	1.98	0.38	4.6
218-219	16.7	13.1		2.43	0.38	3.2
223-224	16.3	16.3	7.3	1.29	0.25	3.2
225-226	19.6	14.4	6.69	0.50	0.15	4.8
230-231	13.89	12.25				
232-233	16.34	13.89				
237-238	19.6	16.34	4.26	0.38	0.25	4.4
239-240	19.6	14.4	5.47	3.04	0.66	4.2
316-317	16.0	15.2	18.0	8.48	1.20	0.52
321-322	20.0	15.2	20.4	9.3	2.1	0.70
323-324	16.4	16.0	10.8	5.85	1.8	0.80
328-329		15.2	8.7	1.43	1.3	0.85

TABLE B-1 REACTOR-CLARIFIER INFLUENT, COMPOSITE SAMPLES, PART 1 (continued)

24 hour composite samples, results in mg/l.

Day	Total Phosphorus as P	Ortho Phosphate Filtrate as P	Total Kjeldahl as N	Ammonia Filtrate as N	Nitrite Filtrate as N	Nitrate Filtrate as N
1970						
330-331	15.2	14.0	10.2	3.15	1.2	0.82
335-336	17.0	15.8	9.0	1.13	0.96	1.0
337-338	15.8	13.6	9.6	4.8	0.79	1.2
342-343	13.0	12.4	19.2	14.7	0.50	0.32
344-345	12.0	10.4	15.0	10.80	0.50	0.77
349-350	16.0	12.4	28.2	22.1	0.08	0.19
351-352	12.0	9.2	24.0	11.9	0.12	0.22
354-355	10.4	9.2	14.4	6.0	3.5	0.29
356-357	15.2	13.6	14.1	12.9	2.8	0.54
363-364	14.4	13.2	14.1	11.9	4.1	0.30
1971						
5-6		7.2	11.1	6.00	2.0	0.5
7-8	12.0	10.4	17.1	11.03	4.00	0.48
12-13	16.4	11.4	9.6	7.35	1.3	1.1
14-15	12.4	11.60	6.3	6.2	0.84	0.65
19-20	18.0	18.0	17.4	11.4	3.5	0.90
21-22	11.4	10.8	18.3	10.5	4.6	0.5
26-27	14.4	13.6	24.9	17.9	2.0	0.55
28-29	6.80	5.6	16.3	15.1	2.15	0.85
33-34	16.0	14.4	22.9	16.2	3.6	2.20
35-36	12.0	11.20	20.8	13.9	2.6	0.8
40-41	13.20	13.20	22.3	13.2	1.3	0.6
47-48	11.4	11.4	15.3	10.8	1.58	0.90
49-50	12.2	10.8	18.3	9.8	2.8	1.0
54-55	12.60	11.40	8.1	7.8	3.0	1.0
56-57	11.8	10.8	8.4	6.2	3.6	0.90
61-62	12.2	12.6	11.4	4.6	4.6	1.5
63-64	14.0	12.0	9.9	1.55	3.7	1.40
68-69	10.4	10.2	8.4	4.1	2.05	1.40
70-71	9.20	8.0	5.7	4.6	1.9	1.50
75-76	11.2	10.4	4.8	1.60	1.55	1.9

TABLE B-1 REACTOR-CLARIFIER INFLUENT, COMPOSITE SAMPLES, PART 1 (continued)

24 hour composite samples, results in mg/l.

Day	Total Phosphorus as P	Ortho Phosphate Filtrate as P	Total Kjeldahl as N	Ammonia Filtrate as N	Nitrite Filtrate as N	Nitrate Filtrate as N
1971						
77-78	10.0	9.6	3.6	3.0	1.7	1.8
82-83	11.2	10.4	11.1	1.8	1.1	1.4
84-85	10.4	9.6	6.0	2.63	0.90	2.4
89-90	10.8	10.8	8.1	3.2	0.82	1.6
91-92	11.4	10.4	27.1	25.9	0.25	2.2
96-97	13.2	12.0	27.7	7.01	0.24	1.60
98-99	11.00	10.80	7.51	3.47	0.78	1.40
103-104	13.2	11.4	5.78	1.37	0.80	1.4
105-106	12.4	10.4	11.56	0.86	0.39	1.6
110-111	13.2	11.6	7.8	0.82	0.31	1.5
112-113	6.40	6.40	12.6	6.08	0.37	1.0
119-120	9.8	9.8				1.3
124-125	13.2	13.2	2.11	1.42	0.78	1.5
126-127	9.8	9.2	6.6	0.94	0.66	1.3
131-132	17.0	14.0	6.9	0.05	0.54	1.5
133-134	11.80	10.2	3.93	0.22	0.88	1.5
140-141	9.60	5.20			0.17	1.5
145-146	13.4	12.2	4.84	0.07	0.54	1.4
147-148	22.0	15.0	5.21	0.27	0.36	1.4
152-153	7.60	6.40	7.82	0.17	0.30	1.70
154-155	12.0	0.57	4.09	0.03	0.76	1.8
159-160	14.0	14.0	4.09	0.15	0.54	1.60
161-162	14.8	14.4	1.86	0.35	0.58	1.7
166-167	13.4	12.2	11.9	5.8	0.65	0.55
168-169	13.4	9.8	11.9	4.90	0.44	0.75
173-174	18.0	10.8	17.5	11.10	0.17	0.42
175-176	12.0	10.4	10.05	9.40	0.15	1.4
180-181	13.20	10.80	10.9	1.10	0.66	0.82
182-183	5.40	2.80	6.03	3.00	0.66	0.66
187-188	11.8	10.0	4.52	1.98	1.30	2.1

TABLE B-1 REACTOR-CLARIFIER INFLUENT, COMPOSITE SAMPLES, PART 1 (continued)

24 hour composite samples, results in mg/l.

Day	Total Phosphorus as P	Ortho Phosphate Filtrate as P	Total Kjeldahl as N	Ammonia Filtrate as N	Nitrite Filtrate as N	Nitrate Filtrate as N
1971						
189-190	30.0	26.0	4.52	0.05	0.39	1.75
194-195	20.0	17.6	4.52	0.24	0.51	0.82
196-197	10.2	9.8	3.77	0.19	0.51	1.10
210-211	14.4	9.8	9.3	6.5	0.46	0.66
215-216	31.0	30.0	10.04	1.05	0.52	0.75
217-218	13.4	10.8	8.56	1.60	0.61	0.50
222-223	12.0	10.4	9.18	8.80	0.20	0.32
224-225	11.2	10.2	13.45	10.17	0.32	0.17

TABLE B-1 REACTOR-CLARIFIER INFLUENT, COMPOSITE SAMPLES, PART 2

24 hour composite samples, results in mg/l.

Day	pH	Alkalinity as $CaCO_3$	Total Hardness as $CaCO_3$	Calcium Filtrate as Ca	Magnesium Filtrate as Mg	Turbidity units
1970						
145-146	7.2	130	390	85.7	42.9	7.4
147-148	7.0	152	390	70.5	52.6	13.0
154-155	7.0	143	400	70.5	55.0	5.5
159-160	6.9	150	392	82.5	45.3	5.0
166-167	7.1	143	390	74.5	49.7	2.4
168-169	7.0	188	410	80.9	50.6	4.6
173-174	7.5	270	398	88.9	42.9	16.0
175-176	7.2	115	394	90.5	40.9	6.4
180-181	7.3	210	390	90.5	39.9	7.2
182-183	7.0	194	390	90.5	39.9	7.5
187-188	7.1	209	400	78.5	49.7	5.4
189-190	7.3	178	380	84.1	41.4	5.5
195-196	6.9	159	376	68.1	50.2	4.0
197-198	6.8	159	390	79.3	46.8	9.0
202-203	7.2	170	376	83.3	40.9	8.0
204-205	7.1	147	394	75.3	50.2	7.0
209-210	7.1	149	396	76.9	49.7	8.0
211-212	7.0	137	376	81.7	41.9	8.0
216-217	7.1	150	390	76.1	48.7	7.0
218-219	7.1	163	374	80.9	41.9	9.5
223-224	7.2	151	374	82.5	40.9	3.0
225-226	7.0	139	364	83.3	38.0	6.5
230-231	7.3	297	374	109.7	24.3	19.0
232-233	7.1	128	368	86.5	37.0	6.0
237-238	7.2	149	374	91.3	35.6	2.4
239-240	7.1	142	374	85.7	39.0	3.4
316-317	7.3	210	386	93.7	37.0	11.0
321-322	7.6	208	402	92.1	41.9	6.0
323-324	7.2	193	402	84.1	46.8	5.0
328-329	7.1	170	386	91.3	38.5	9.7

TABLE B-1 REACTOR-CLARIFIER INFLUENT, COMPOSITE SAMPLES, PART 2 (continued)

24 hour composite samples, results in mg/l.

Day	pH	Alkalinity as $CaCO_3$	Total Hardness as $CaCO_3$	Calcium Filtrate as Ca	Magnesium Filtrate as Mg	Turbidity units
1970						
330-331	7.3	182	380	84.9	40.9	9
335-336	7.3	160	406	108	33.1	6
337-338	7.2	162	396	92.1	40.4	6
342-343	7.5	290	376	76.1	45.3	10
344-345	7.3	207	380	77.7	45.3	9
349-350	7.4	326	394	81.7	46.3	14
351-352	7.6	290	390	116.1	24.3	7
354-355	7.5	270	404	88.1	44.8	7
356-357	7.2	218	430	90.5	49.7	10
363-364	7.2	275	410	86	75	8
1971						
5-6	7.3	198	420	94.8	44.8	7
7-8	7.3	223	410	91.3	44.3	5
12-13	7.2	153	420	101.7	40.4	8
14-15	7.3	178	412	92.9	43.8	8
19-20	7.4	235	446	102.5	46.3	7
21-22	7.4	243	410	100.1	39.0	8
26-27	7.6	274	418	85.7	49.7	7
28-29	7.5	253	410	97.7	40.4	9
33-34	7.5	249	422	103.3	39.9	9.6
35-36	7.1	218	412	99.3	39.9	8
40-41	7.5	278	406	99.3	12.77	9
47-48	7.7	303	406	105.7	34.6	8
49-50	7.6	257	408	104.1	36.0	5
54-55	7.4	236	410	93.7	42.9	9.5
56-57	7.6	230	416	101.7	39.4	8.4
61-62	7.3	171	414	97.7	41.4	9.0
63-64	7.3	149.6	434	112.9	37.0	6
68-69	7.4	166	414	92.1	44.8	7
70-71	7.6	166	408	92.9	42.9	5
75-76	7.2	139	406	87.3	45.8	3

TABLE B-1 REACTOR-CLARIFIER INFLUENT, COMPOSITE SAMPLES, PART 2 (continued)

24 hour composite samples, results in mg/l.

Day	pH	Alkalinity as $CaCO_3$	Total Hardness as $CaCO_3$	Calcium Filtrate as Ca	Magnesium Filtrate as Mg	Turbidity units
1971						
77-78	7.1	140	410	96.9	40.9	4
82-83	7.3	133.7	432	96.9	46.3	5
84-85	7.4	154	416	105.7	37.0	
89-90	7.2	154	416	87.3	48.2	8.5
91-92	7.3	139.6	412	88.9	46.3	8.0
96-97	7.1	112	424	101.7	41.4	7
98-99	7.3	113	418	93.7	44.8	5
103-104	7.3	114	406	88.9	44.8	13
105-106	7.2	105.6	408	92.9	42.9	11
110-111	7.3	148	454	94.5	53.1	17
112-113	7.4	210.5	416	92.9	44.8	20
119-120	7.4		402	91.3	42.4	8
124-125	7.4	146.3	428	102.5	41.9	8
126-127	7.0	138.4	408	99.3	39.0	8
131-132	7.4	177.9	400	94.5	39.9	8
133-134	7.2	143.7	400	91.3	41.9	7
140-141	7.3	130.5	402	89.7	43.3	10
145-146	7.2	136.8	398	94.5	39.4	5
147-148		68.4	426	106.5	39.0	97.0
152-153	7.5	130.3	420	99.3	41.9	7
154-155	7.5	118.9	398	90.5	41.9	6
159-160	7.3	117.3	412	101.7	38.5	9.5
161-162	7.5	117.3	438	96.9	47.7	6
166-167	7.6	236	396	87.3	43.3	8
168-169	7.3	197.0	398	91.3	41.4	7
173-174	7.4	244.4	384	82.5	43.3	5.0
175-176	7.3	244.4	370	94.5	32.6	7.5
180-181	7.2	188.7	394	83.3	45.3	10.1
182-183	7.6	175.6	416	88.1	47.7	10
187-188	7.6	144.4	388	87.3	41.4	8.0

TABLE B-1 REACTOR-CLARIFIER INFLUENT, COMPOSITE SAMPLES, PART 2 (continued)

24 hour composite samples, results in mg/l.

Day	pH	Alkalinity as $CaCO_3$	Total Hardness as $CaCO_3$	Calcium Filtrate as Ca	Magnesium Filtrate as Mg	Turbidity units
1971						
189-190	7.5	123.1	396	85.7	44.3	9.0
194-195	7.3	144.4	386	87.3	40.9	16.0
196-197	7.1	132.9	384	84.9	41.9	10.0
210-211	7.1	212.6	390	94.5	37.5	6.0
215-216	7.3	165.1	384	87.3	40.4	7
217-218	7.3	157.0	386	90.5	39.0	8.0
222-223	7.4	238.1	378	91.3	36.5	7
224-225	7.3	248.3	382	90.5	38.0	8

TABLE B-1 REACTOR-CLARIFIER INFLUENT, COMPOSITE SAMPLES, PART 3

24 hour composite samples, results in mg/l.

Day	Suspended Solids	Volatile Suspended Solids	COD	COD Filt.	BOD	Color units	Conductivity 10^{-6}mohs cm	Methylene Blue Active Substs.
1970								
145-146	44		47.7	35.1				
147-148	65		86.2	28.7		45		
154-155	108		43.6	32.9		40		
159-160	111		34.3	27.0				
166-167	62		48.2	43.0				
168-169	126		50.7	50.1		40		
173-174	124		100	100				
175-176	55		127	95		40		
180-181	86		65.5	53.8				
182-183	131		69.7	57.7		40		
187-188	43		84.9	77.7				
189-190	154		63.1	43.7		40		
195-196	57		65.3	57.8				
197-198	36		115	80.1		45		
202-203	38		67.1	60.3				
204-205	40		68.4	44.7	3.15	40		
209-210	18		44.0	36.5	7.97			
211-212	12		39.7	34.3		45		
216-217	55		63.7	37.1	2.88			
218-219	21		59.2	44.7		35		
223-224	6		34.8	32.8	6.5			.07
225-226	38	18	40.7	38.3	7.5	35		
230-231	108	81	133	95.8		45	1610	1.66
232-233	52	36	37.9	36.4	8.67	30	1630	
237-238	33	28	31.1	30.4		30	1590	.06
239-240	44	25	37.0	30.3	6.0	35	1170	
316-317	89	29	71.0	42.6			1550	
321-322	76	40	61.3	48.4	17.4	40	1550	.20
323-324	59	35	73.5	56.6		45	1580	
328-329	66	19	57.5	47.1	19.3		1570	.18

TABLE B-1 REACTOR-CLARIFIER INFLUENT, COMPOSITE SAMPLES, PART 3 (continued)

24 hour composite samples, results in mg/l.

Day	Suspended Solids	Volatile Suspended Solids	COD	COD Filt.	BOD	Color units	Conductivity 10^{-6} mohs/cm	Methylene Blue Active Substs.
1970								
330-331	81	66	91.0	57.3			1520	
335-336	51	29	55.8	39.3	46.0	35	1650	.18
337-338	24	13	58.9	40.8			1360	
342-342	63	27	76.5	49.2	24.0	35	1730	1.6
344-345	84	46	74.6	47.2			1630	
349-350	69	54	114	74.7	59.4	35	1780	2.1
351-352	31	28	80.8	62.1			1690	
354-355	68	39	68.2	51.5			1730	
356-357	43	31	62.0	51.2		45	1720	.50
363-364	64	33	69.2	62.7	14.0	40	1650	.55
1971								
5-6	70	18	83.2	63.4	39.4	40	1700	.18
7-8	50	18	57.9	47.0			1760	
12-13	46	26	71.0	47.6	40.0	45	1750	.25
14-15	53	24	86.1	65.2			1750	
19-20	86	39	86.4	62.6	42.7	45	1780	.20
21-22	40	23	70.7	58.9			1770	
26-27	73	21	83.5	68.3	40.7	30	1320	.25
28-29	65	29	71.4	50.0			1760	
33-34	48	19	59.9	55.4	45.4	40	1860	.16
35-36	25	15	43.3	33.1			1800	
40-41	56	25	65.2	53.9		40	1780	.75
47-48	14	11	48.6	38.8	34.7	25	1820	.22
49-50	21	12	56.4	30.6			1720	
54-55	25	15	52.5	43.0	46.7	30	1630	.30
56-57	18	12	55.7	47.1			1690	
61-62	31	9	60.1	46.2	28.0	40	1710	.25
63-64	29	16	64.5	55.0			1780	
68-69	25	18	51.2	43.6	28.0	35	1770	.20
70-71	28	23	58.8	46.3			1740	
75-76	50	28	45.0	36.6		30	1800	.46

TABLE B-1 REACTOR-CLARIFIER INFLUENT, COMPOSITE SAMPLES, PART 3 (continued)

24 hour composite samples, results in mg/l.

Day	Suspended Solids	Volatile Suspended Solids	COD	COD Filt.	BOD	Color units	Conductivity 10^{-6} mohs/cm	Methylene Blue Active Substs.
1971								
77-78	60	45	50.6	41.3		40	1760	
82-83	21	12	61.3	50.6	24.7	40	1750	.21
84-85	51	40	48.1	31.6				
89-90	40	37	45.3	35.0	24.7	45	1770	.25
91-92	52	35	49.0	36.8			1760	
96-97	41	35	55.1	33.7	18.7	40	1780	.20
98-99	32	25	53.5	40.4			1490	
103-104	61	33	62.0	38.2	27.3	35	1650	.10
105-106	50	41	74.6	52.4			2110	
110-111	77	46	70.1	46.5	32.0	20	1680	.20
112-113	87	56	86.9	59.7			1750	
119-120	21						1730	
124-125	39	27	66.0	52.8		30	1770	.02
126-127	36	27	51.8	35.7			1720	
131-132	35	21	48.8	36.3	16.0	30	1750	.07
133-134	34	19	47.4	34.4			1810	
140-141	42	33	53.0	35.8			1770	
145-146	36	11	34.5	23.1	16.7	35	1750	.04
147-148	243	85	47.1	35.4			1720	
152-153	37	25	40.7	31.7	15.3	40	1760	.03
154-155	48	25	48.3	40.0			1700	
159-160	52	34	47.3	36.9	7.34	35	1780	.03
161-162	38	31	53.5	45.4			1760	
166-167	40	17	50.6	39.6	30.0	30	1800	.20
168-169	36	26	37.4	24.8			1760	
173-174	52	37	55.8	47.0		40	1760	.20
175-176	43	29	53.5	38.1	37.4		1760	
180-181	52	35	45.2	32.3		40	1720	.20
182-183	59	42	52.6	40.3	36.7		1480	
187-188	44	41	37.4	27.7	9.3	25	1500	.20

TABLE B-1 REACTOR-CLARIFIER INFLUENT, COMPOSITE SAMPLES, PART 3 (continued)

24 hour composite samples, results in mg/1.

Day	Suspended Solids	Volatile Suspended Solids	COD	COD Filt.	BOD	Color units	Conductivity 10^{-6}mohs / cm	Methylene Blue Active Substs.
1971								
189-190	50	43	62.7	49.1			1740	
194-195	62	56	76.9	44.9	31.3	30		.23
196-197	46	35	50.2	29.8			1830	
210-211	40	31	45.3	25.7			1720	
215-216	46	32	52.0	41.5	26.0	30	1680	.15
217-218	60	41	53.2	35.3			1460	
222-223	47	26	42.6	38.5	18.7	30	1800	.20
224-225	40	25	51.4	33.7				

TABLE B-2 REACTOR-CLARIFIER EFFLUENT, COMPOSITE SAMPLES, PART 1

24 hour composite samples, results in mg/l.

Day	Total Phosphorus as P	Ortho Phosphate Filtrate as P	pH	Alkalinity as $CaCO_3$	Total Hardness as $CaCO_3$
1970					
145-146		0.20	10.4	163	342
147-148		0.26	11.1	220	394
154-155		0.81	11.1	283	405
159-160		0.51	10.7	180	338
166-167		0.29	10.6	189	318
168-169		1.09	10.5	250	296
173-174		0.00	10.8	180	268
175-176		0.24	10.2	195	290
180-181		0.16	10.5	200	365
182-183		0.47	10.3	152	302
187-188	18.5	5.7	8.2	146	318
189-190		0.13	10.0	115	302
195-196		0.00	9.6	108	354
197-198	0.42	0.00	9.8	81.4	296
202-203			10.3	90	288
204-205	0.31	0.23	10.0	91	306
209-210		0.03	9.9	149	342
211-212	0.85	0.56	10.0	102	370
216-217		0.12	10.0	139	364
218-219	0.72	0.19	9.5	147	362
223-224		0.24	9.9	111	310
225-226	0.65	0.10	9.9	98.2	306
230-231	0.19	0.14	9.8	152	276
232-233	0.49	0.33	9.9	105	316
237-238	0.08	0.04	9.6	40.7	256
239-240	0.72	0.12	9.4	40.7	262
316-317	0.96	0.27	10.3	198	334
321-322	1.0	0.76	10.2	186	358
323-324	0.90	0.40	10.4	169	344
328-329		0.60	11.0	231	326

TABLE B-2 REACTOR-CLARIFIER EFFLUENT, COMPOSITE SAMPLES, PART 1 (continued)

24 hour composite samples, results in mg/l.

Day	Total Phosphorus as P	Ortho Phosphate Filtrate as P	pH	Alkalinity as $CaCO_3$	Total Hardness as $CaCO_3$
1970					
330-331	2.7	2.0	10.0	230	336
335-336	3.4	1.0	10.0	169	374
337-338	1.0	0.40	9.9	168	362
342-343	1.28	0.68	9.9	217	296
344-345	2.10	0.90	10.8	375	326
349-350	1.60	0.46	10.7	271	294
351-352	2.0	0.56	10.3	223	310
354-355	9.6	4.6	9.0	338	432
356-357	6.8	4.6	9.6	233	418
363-364	0.82	0.28	11.3	399	438
1971					
5-6		0.11	10.4	153	328
7-8	0.54	0.15	10.1	232	338
12-13	1.2	0.14	10.8	146	352
14-15	0.40	0.10	10.2	136	338
19-20	1.8	0.34	10.0	187	364
21-22	0.94	0.40	9.8	190	344
26-27	1.65	1.30	10.1	192	362
28-29	0.85	0.25	10.1	195	338
33-34	1.90	1.00	9.8	218	376
35-36	1.60	0.64	9.8	220	366
40-41	1.75	0.62	10.1	206	342
47-48	1.75	0.56	9.6	222	390
49-50	1.05	0.30	10.3	212	340
54-55	0.80	0.21	10.3	197	352
56-57	0.74	0.44	10.4	189	352
61-62	1.5	0.27	10.1	188	380
63-64	1.80	0.36	9.6	166.8	398
68-69	2.0	0.94	9.6	188	416
70-71	1.40	0.48	9.7	201	412
75-76	2.1	0.34	10.1	171	418

TABLE B-2 REACTOR-CLARIFIER EFFLUENT, COMPOSITE SAMPLES, PART 1 (continued)

24 hour composite samples, results in mg/l.

Day	Total Phosphorus as P	Ortho Phosphate Filtrate as P	pH	Alkalinity as $CaCO_3$	Total Hardness as $CaCO_3$
1971					
77-78	2.0	0.70	9.5	171	422
82-83	2.1	0.74	9.6	177.4	432
84-85	2.0	0.64	9.8	201	430
89-90	0.72	0.35	9.8	195	384
91-92	0.74	0.40	9.8	172.6	428
96-97	0.98	0.36	9.9	110.5	414
98-99	0.74	0.67	9.6	145	438
103-104	2.2	2.2	9.7	20.4	422
105-106	2.1	0.98	9.7	7.2	414
110-111	2.3	1.25	9.4	103.4	420
112-113	2.60	1.40	8.9	148.3	440
119-120	2.2	1.1	9.2		414
124-125	0.94	0.42	9.7	71.3	398
126-127	1.28	0.58	9.2	71.2	424
131-132	2.2	1.28	9.5	117.4	408
133-134	2.2	1.3	9.5	93.7	404
140-141	2.20	2.0	9.4	91.5	396
145-146	0.92	0.88	9.4	122.9	400
147-148	3.60	0.59	11.0	52.5	366
152-153	0.17	0.06	11.3	45.4	344
154-155	0.14	0.10	11.8	188.5	534
159-160	0.24	0.14	11.8	91.5	492
161-162	0.25	0.11	10.7	58.1	452
166-167	0.23	0.23	10.1	36.0	310
168-169	0.77	0.19	9.9	62.0	334
173-174	0.56	0.17	10.3	68.3	292
175-176	0.18	0.07	10.6	73.0	296
180-181	0.87	0.046	10.4	61.5	322
182-183	0.39	0.04	10.0	54.8	328
187-188	0.71	0.67	10.8	62.7	374

TABLE B-2 REACTOR-CLARIFIER EFFLUENT, COMPOSITE SAMPLES, PART 1 (continued)

24 hour composite samples, results in mg/l.

Day	Total Phosphorus as P	Ortho Phosphate Filtrate as P	pH	Alkalinity as $CaCO_3$	Total Hardness as $CaCO_3$
1971					
189-190	1.5	1.1	11.1	112.6	472
194-195	0.98	0.32	10.9	59.5	390
196-197	0.25	0.15	10.7	55.6	382
210-211	1.72	0.51	9.7	69.8	344
215.216	1.35	1.35	10.6	54.8	310
217-218		0.21	10.5	43.0	344
222-223	0.30	0.11	10.3	60.5	282
224-225	0.22	0.18	10.3	61.8	298

TABLE B-2 REACTOR-CLARIFIER EFFLUENT, COMPOSITE SAMPLES, PART 2

24 hour composite samples, results in mg/l.

Day	Calcium Filtrate as Ca	Magnesium Filtrate as M	Turbidity units	Suspended Solids
1970				
145-146	100.9	21.9		37
147-148	138	12.2		46
154-155	142	12.2		45
159-160	125	6.33		64
166-167	107	12.7		48
168-169	98.5	12.2		84
173-174	98.5	5.4		66
175-176	92.9	14.1		45
180-181	116.1	18.5		52
182-183	101.7	11.7	10.2	47
187-188	87.3	31.2		42
189-190	97.7	14.1	1.5	51
195-196	81.7	36.5	9.0	51
197-198	98.5	12.2	11.0	22
202-203	96.9	11.2	3.5	23
204-205	92.1	18.5	4.5	24
209-210	92.9	26.9	6	12
211-212	93.7	33.1	6.0	11
216-217	83.3	38.0	10.0	40
218-219	88.1	34.6	5.0	14
223-224	90.5	20.5	5.0	6
225-226	88.9	20.5	6.0	14
230-231	65.7	27.3	6.0	27
232-233	92.9	20.5	5.0	17
237-238	86.5	9.74	1.5	9
239-240	82.5	13.64	10	25
316-317	110.5	14.1	18	66
321-322	103	24.4	22.0	52
323-324	106.5	19.0	5.5	47
328-329	118.5	7.30	28.0	103

TABLE B-2 REACTOR-CLARIFIER EFFLUENT, COMPOSITE SAMPLES, PART 2 (continued)

24 hour composite samples, results in mg/l.

Day	Calcium Filtrate as Ca	Magnesium Filtrate as M	Turbidity units	Suspended Solids
1970				
330-331	85.7	29.7	72	271
335-336	103	28.7	28	86
337-338	97.7	27.3	8	31
342-343	76.1	25.8	8	32
344-345	116	8.8	10.2	582
349-350	93.7	14.6	32	119
351-352	84.1	24.3	43	149
354-355	100.9	43.8	62	105
356-357	111	34.1	36	88
363-364	187	40	16	77
1971				
5-6	102.5	17.5	18	89
7-8	92.9	25.8	70	213
12-13	125.18	9.3	11	30
14-15	103.3	19.5	17	48
19-20	102.5	26.3	90	452
21-22	83.3	31.1	8	24
26-27	100.9	26.8	29	93
28-29	96.9	23.4	23	143
33-34	90.5	36.5	30.0	153
35-36	95.3	31.2	2.2	87
40-41	93.7	26.3	18	78
47-48	108.1	29.2	14.0	58
49-50	92.9	26.3	19	38
54-55	92.1	29.7	11.0	81
56-57	90.5	30.7	9.0	42
61-62	100.9	31.2	24	76
63-64	107.3	31.7	13	37
68-69	108.1	35.6	26	38
70-71	100.9	39.0	10	37
75-76	110.5	34.6	21	111

TABLE B-2 REACTOR-CLARIFIER EFFLUENT, COMPOSITE SAMPLES, PART 2 (continued)

24 hour composite samples, results in mg/l.

Day	Calcium Filtrate as Ca	Magnesium Filtrate as M	Turbidity units	Suspended Solids
1971				
77-78	108.9	36.5	13	85
82-83	112.1	37.1	21	49
84-85	111.3	37.0		66
89-90	104	30.2	16.0	114
91-92	150.6	12.7	5.0	43
96-97	109.7	34.1	10	42
98-99	110.5	39.4	5.7	35
103-104	105.7	38.5	24	58
105-106	112.9	32.1	28	51
110-111	115	32.6	32	51
112-113	108.1	41.4	22	68
119-120	104.1	37.5	15	25
124-125	106.5	32.1	8	52
126-127	109.7	36.5	11	59
131-132	104.9	35.6	22	53
133-134	100.9	37.0	20	56
140-141	91.3	40.9	47	105
145-146	96.1	39.0	8	41
147-148	124.2	13.64	35.0	106
152-153	131.4	3.90	3	46
154-155	207.5	3.90	8	58
159-160	193.8	1.95	7.4	46
161-162	177.0	2.43	6	42
166-167	94.5	18.0	4	51
168-169	106.5	16.56	9	57
173-174	100.1	10.23	16.0	49
175-176	103.3	9.25	5.0	36
180-181	115.3	8.3	25.0	72
182-183	98.5	20.0	7.5	42
187-188	148.2	0.97	5.0	43

TABLE B-2 REACTOR-CLARIFIER EFFLUENT, COMPOSITE SAMPLES, PART 2 (continued)

24 hour composite samples, results in mg/l.

Day	Calcium Filtrate as Ca	Magnesium Filtrate as M	Turbidity units	Suspended Solids
1971				
189-190	185.0	2.43	6.8	45
194-195	151.4	2.92	5	60
196-197	146.6	3.90	4.6	37
210-211	96.9	24.84	27	76
215-216	118.5	3.41	3	49
217-218	131.4	3.90	3.0	33
222-223	96.1	10.23	7	54
224-225	95.3	14.6	3	40

TABLE B-2 REACTOR-CLARIFIER EFFLUENT, COMPOSITE SAMPLES, PART 3

24 hour composite samples, results in mg/l.

Day	COD	COD Filtrate	BOD	Color units	Conductivity 10^{-6}mohs/cm
1970					
145-146					
147-148					
154-155					
159-160					
166-167					
168-169					
173-174					
175-176					
180-181					
182-183					
187-188					
189-190					
195-196					
197-198					
202-203					
204-205					
209-210					
211-212					
216-217					
218-219					
223-224					
225-226					
230-231	43.1	40.3		35	1520
232-233	35.5	34.6		20	1470
237-238	20.9	20.6		15	1400
239-240	18.9	18.9		15	1090
316-317	33.5	30.2			1600
321-322	42.9	35.6		30	1410
323-324	45.2	40.0		35	1250
328-329	41.3	41.3	1.50		1570

TABLE B-2 REACTOR-CLARIFIER EFFLUENT, COMPOSITE SAMPLES, PART 3 (continued)

24 hour composite samples, results in mg/l.

Day	COD	COD Filtrate	BOD	Color units	Conductivity 10^{-6}mohs/cm
1970					
330-331	59.2	44.1			1170
335-336	35.5	32.3	2.67	25	1100
337-338	34.7	30.4			1560
342-343	43.9	40.7	3.5	25	1500
344-345	66.3	32.1			1580
349-350	43.9	43.1	3.5	25	1500
351-352	44.5	38.1			1580
354-355	57.4	50.5			1470
356-357	46.2	37.7		30	1650
363-364	39.0	37.6	3.5	25	1530
1971					
5-6	52.7	45.1	1.34	20	1510
7-8	51.6	37.6			1460
12-13	36.7	33.7	1.84	20	1650
14-15	45.7	40.8			1600
19-20	79.8	47.7	3.67	15	1580
21-22	46.5	39.7			1670
26-27	57.6	57.6	2.50	30	1240
28-29	35.4	31.7			1520
33-34	49.6	48.7	1.67	15	1670
35-36	29.2	27.1			1670
40-41	41.8	36.2		25	1610
47-48	32.6	31.3	2.34	15	1540
49-50	44.0	32.9			1560
54-55	36.1	35.3	1.16	25	1650
56-57	38.1	37.1			1580
61-62	40.0	39.2	7.5	35	1630
63-64	49.5	42.6			1670
68-69	44.0	32.0	9.2	20	1720
70-71	41.5	40.0			1720
75-76	36.6	30.4		25	1760

TABLE B-2 REACTOR-CLARIFIER EFFLUENT, COMPOSITE SAMPLES, PART 3 (continued)

24 hour composite samples, results in mg/l.

Day	COD	COD Filtrate	BOD	Color units	Conductivity 10^{-6}mohs/cm
1971					
77-78	38.6	37.7		30	1750
82-83	52.8	44.2	2.84	25	1750
84-85	30.0	26.6			
89-90	33.0	26.8	2.2	35	1640
91-92	28.3	27.3			1700
96-97	32.6	30.3	2.3	30	1760
98-99	29.3	27.0			1730
103-104	30.1	24.6	7.35		1640
105-106	46.4				1720
110-111	36.5	29.4	8.0	10	1680
112-113	61.8	54.0			1710
119-120					1730
124-125	45.2	44.0		30	1730
126-127	32.1	29.3			1720
131-132	32.2	31.8	4.2	20	1680
133-134	33.9	30.0			1780
140-141	33.5	27.4			1710
145-146	26.4	23.1	2.34	25	1700
147-148	28.0	24.1			1710
152-153	23.0		1.6	15	1800
154-155	27.6	26.7			2430
159-160	28.7	24.8	0.5	10	2330
161-162	32.3	31.6			2150
166-167	31.4	30.2	1.34	20	1610
168-169	20.7	19.6			1650
173-174	35.4	35.4		20	1610
175-176	31.8	29.9	1.2		1650
180-181	21.0	17.9		15	1790
182-183	27.3	27.3	2.67		1400
187-188	16.5	16.1	0.50	15	2030

TABLE B-2 REACTOR-CLARIFIER EFFLUENT, COMPOSITE SAMPLES, PART 3 (continued)

24 hour composite samples, results in mg/l.

Day	COD	COD Filtrate	BOD	Color units	Conductivity 10^{-6}mohs/cm
1971					
189-190	33.9	33.4			2490
194-195	23.8	23.4	1.34	10	
196-197	20.2	18.2			2140
210-211	32.2	23.7			1580
215-216	22.1	22.1	1.0	10	1780
217-218	24.7	23.1			1550
222-223	26.3	25.9	1.5	15	1680
224-225	23.1	20.4			

TABLE B-3 DUAL-MEDIA FILTERS INFLUENT, COMPOSITE SAMPLES, PART 1

24 hour composite samples, results in mg/l.

Day	Ortho Phosphate Filtrate as P	pH	Alkalinity as $CaCO_3$	Total Hardness as $CaCO_3$
1970				
145-146	0.26	7.2	115	336
147-148	0.25	7.2	90	304
154-155	0.81	7.5	148	375
159-160	0.92	7.6	142	380
166-167	0.31	6.9	115	348
168-169	2.90	7.1	140	308
173-174	0.65	7.4	121	248
175-176	0.23	7.4	122	296
180-181	1.50	7.1	165	354
187-188	1.05	7.1	146	318
189-190	0.42	7.2	102	306
195-196	0.24	6.8	95	294
197-198	0.41	7.1	73	134
202-203	0.23	7.0	83	260
204-205	0.31	7.5	112	346
209-210	0.85	7.3	107	348
211-212	2.55	7.4	107	288
216-217	0.95	7.5	163	338
218-219	0.56	7.0	154	370
223-224	0.39	7.0	121	316
225-226	0.49	7.0	104	316
230-231	0.62	7.2	143	312
232-233	0.26	7.3	157	336
237-238	0.85	7.5	136	340
239-240	0.29	7.3	118	324
316-317	1.0	7.5	245	388
342-343	1.20	8.5	219	296
344-345	0.76	9.3	194	322
349-350	1.48	9.3	282	326
351-352	0.50	9.4	269	354

TABLE B-3 DUAL-MEDIA FILTERS INFLUENT, COMPOSITE SAMPLES, PART 1 (continued)

24 hour composite samples, results in mg/l.

Day	Ortho Phosphate Filtrate as P	pH	Alkalinity as $CaCO_3$	Total Hardness as $CaCO_3$
1970				
356-357	3.5	8.9	247	426
1971				
7-8	0.40	8.2	238	394
12-13	0.39	7.8	170	402
14-15	0.22	8.2	141	356
28-29	0.25	9.3	231	
33-34	0.82	9.1	264	
35-36	0.21	9.9	237	
40-41	1.35	7.8	227	
47-48	2.20	8.2	300	
49-50	0.88	8.4	260	374
54-55	0.66	7.3	240	382
56-57	0.85	7.8	238	386
61-62	1.5	7.8	229	434
63-64	0.98	8.0	194.6	450
68-69	1.90	7.8	204	430
70-71	0.88	8.2	211	440
75-76	1.70	8.4	201	436
77-78	1.35	8.4	218	460
82-83	2.0	8.0	214.5	460
84-85	2.0	7.9	224	464
89-90	1.15	8.3	203	418
96-97	1.75	7.4	138	424
98-99	0.88	7.9	152	438
103-104	2.0	8.2	183.6	444
105-106	2.10	8.1	159.6	440
110-111	2.2	8.4	201	442
112-113	2.60	7.6	233	450
119-120	2.2	7.4		434
124-125	1.05	8.1	171.3	418
126-127	1.28	7.7	191.1	446
131-132	2.0	8.0	204	426

TABLE B-3 DUAL-MEDIA FILTERS INFLUENT, COMPOSITE SAMPLES, PART 1 (continued)

24 hour composite samples, results in mg/1.

Day	Ortho Phosphate Filtrate as P	pH	Alkalinity as $CaCO_3$	Total Hardness as $CaCO_3$
1971				
133-134	2.0	7.9	197.7	434
140-141	2.0	7.9	222.7	428
145-146	1.55	7.7	177.6	406
147-148	2.30	9.6	68.4	406
152-153	0.46	8.0	158.0	384
154-155	0.33	9.0	96.1	398
159-160	0.18	9.0	81.5	388
161-162	0.11	8.2	158	408
166-167	0.35	8.6	153.1	332
168-169	1.85	8.3	154.8	378
173-174	0.46	8.5	127.1	298
175-176	0.28	8.3	131.9	278
182-183	0.37	8.1	169.0	380
187-188	0.94	8.5	88.6	338
189-190	1.2	8.1	106.7	352
194-195	1.10	8.2	121.4	368
196-197	0.25	8.5	109.8	384
210-211	1.5	7.7	181.5	358
215-216	1.30	8.5	153.5	352
217-218	0.62	8.6	82.7	338
222-223	0.13	8.8	118.4	286
224-225	0.12	8.8	75.5	296

TABLE B-3 DUAL-MEDIA FILTERS INFLUENT, COMPOSITE SAMPLES, PART 2

24 hour composite samples, results in mg/l.

Day	Calcium Filtrate as Ca	Magnesium Filtrate as Mg	Turbidity units	Suspended Solids
1970				
145-146	104.1	18.5		30
147-148	95.3	16.1		34
154-155	105	27.2		39
159-160	126	16.1		32
166-167	106	20.5		31
168-169	92.1	19.0		27
173-174	86.5	7.3		30
175-176	103.3	9.2		32
180-181	112.9	17.5		37
187-188	102	15.6		38
189-190	105.7	10.2	1.5	35
195-196	67.3	30.7	0.3	33
197-198	35.2	11.2	0.6	14
202-203	85.7	11.2	8.6	14
204-205	95.3	26.3	0.45	22
209-210	115	14.6	2	11
211-212	63.3	31.7	0.5	10
216-217	84.9	30.7	0.5	19
218-219	97.7	30.7	0.4	10
223-224	101	15.6	0.35	19
225-226	93.7	20.0	0.3	8
230-231	95.3	18.0	0.55	11
232-233	107	16.6	1.0	18
237-238	109.7	16.1	0.34	4
239-240	104.9	15.1	0.2	5
316-317	94.5	37.0	8	46
342-343	76.1	25.8	9	16
344-345	106	13.6	10	93
349-350	94.5	21.2	28	114
351-352	95.3	28.2	9	41

TABLE B-3 DUAL-MEDIA FILTERS INFLUENT, COMPOSITE SAMPLES, PART 2 (continued)

24 hour composite samples, results in mg/l.

Day	Calcium Filtrate as Ca	Magnesium Filtrate as Mg	Turbidity units	Suspended Solids
1970				
356-357	123	28.7	10	43
1971				
7-8	106.5	31.2	30	94
12-13	130.6	18.5	11	25
14-15	106.5	21.9	3	22
28-29			2	25
33-34			6.0	79
35-36			0.8	38
40-41			3	20
47-48			6.0	15
49-50	106.5	26.3	2	11
54-55	101.7	31.2	4.6	19
56-57	108.1	28.2	3.2	21
61-62	128	27.8	4.0	16
63-63	131.4	29.7	3	8
68-69	114.7	35.6	3	12
70-71	119.3	34.6	4	18
75-76	126.6	29.2	4	41
77-78	128.2	34.1	2	29
82-83	125.0	36.0	3	20
84-85	125.8	36.5	2.6	30
89-90	127	24.4	2.0	51
96-97	110.5	36.0	3	24
98-99	111.3	39.0	5.0	26
103-104	116.1	37.5	4	37
105-106	118.5	35.1	4	30
110-111	116	37.0	4	31
112-113	117.7	38.0	8	39
119-120	108.1	39.9	3.3	2
124-125	107.3	36.5	3	28
126-127	120.1	35.6	3	29
131-132	110.5	36.5	3.8	24

TABLE B-3 DUAL-MEDIA FILTERS INFLUENT, COMPOSITE SAMPLES, PART 2 (continued)

24 hour composite samples, results in mg/l.

Day	Calcium Filtrate as Ca	Magnesium Filtrate as Mg	Turbidity units	Suspended Solids
1971				
133-134	115.3	35.6	3.0	28
140-141	109.7	37.5	5	31
145-146	100.1	38,0	3	25
147-148	125.8	22.4	99.0	294
152-153	146.6	4.38	2	32
154-155	154.6	2.92	20	126
159-160	153.8	0.97	13.0	179
161-162	159.4	2.43	23	156
166-167	105.7	16.56	7	110
168-169	116.9	20.94	3	45
173-174	100.9	11.20	10.0	41
175-176	98.5	7.79	7.0	23
182-183	88.9	38.5	4.0	97
187-188	131.4	2.43	5.0	40
189-190	138.6	1.46	1.0	32
194-195	117.7	18.0	40	139
196-197	146.6	4.38	12	68
210-211	102.5	24.84	10	49
215.216	133.0	4.87	4	34
217-218	127.4	4.87	5.0	23
222-223	96.9	10.71	8	44
224-225	88.9	18.02	10	36

TABLE B-4 DUAL-MEDIA FILTERS EFFLUENT, COMPOSITE SAMPLES, PART 1

24 hour composite samples, results in mg/l.

Day	Total Phosphorus as P	Ortho Phosphate Filtrate as P	Total Kjeldahl as N	Ammonia Filtrate as N	Nitrite Filtrate as N	Nitrate Filtrate as N
1970						
145-146	0.52	0.36		0.91		
146-147						
147-148	0.43	0.31				
153-154						
154-155	1.50	1.09				
155-156						
159-160	1.09	1.09	3.95	0.56		1.0
160-161						
162-163						
168-169	2.84	2.61				
169-170						
173-174	0.33	0.16		8.36		0.26
174-175						
175-176	0.39	0.26				
176-177						
180-181	1.09	0.98				
181-182						
187-188	1.83	0.98		6.44		15.0
188-189						
189-190	0.57	0.49				
190-191						
194-195						
195-196	1.11	0.78	10.0	3.34	1.25	2.0
196-197						
197-198	0.33	0.25				
201-202				5.62	1.15	20.0
202-203	0.28	0.11	3.65	0.91	0.35	0.35
203-204						5.4
204-205	0.29	0.23				
208-209				5.55	0.30	4.0

TABLE B-4 DUAL-MEDIA FILTERS EFFLUENT, COMPOSITE SAMPLES, PART 1 (continued)

24 hour composite samples, results in mg/1.

Day	Total Phosphorus as P	Ortho Phosphate Filtrate as P	Total Kjeldahl as N	Ammonia Filtrate as N	Nitrite Filtrate as N	Nitrate Filtrate as N
1970						
209-210	0.69	0.46	2.74	1.19	0.20	4.4
211-212	2.50	0.82				
215-216			1.22	0.59	0.16	4.4
216-217	0.98	0.46	1.52	0.08	0.05	4.0
218-219						
218-219	0.82	0.59				
222-223	0.88		7.60	0.53	0.16	2.8
223-224	0.52	0.52	4.26	0.73	0.10	3.2
224-225	0.52		3.65	0.56	0.10	4.0
225-226	0.46	0.36	3.04	0.14	0.01	4.4
229-230	0.65		4.56	1.31	0.07	5.2
230-231	0.56	0.49				
231-232	1.4		21.58	12.46	0.13	0.48
232-233	0.23	0.20				
236-237	0.63		4.26	0.69	0.20	4.8
237-238	0.95	0.95	3.04	0.50	0.04	5.2
238-239	1.3		4.26	0.96	0.03	4.4
239-240	0.39	0.24	3.65	1.52	0.09	4.0
317-318	0.96	0.96	15.3	6.00	1.15	0.55
341-342	1.65		12.90	10.43	0.20	0.37
342-343	0.65	0.60	12.9	12.4	0.70	0.32
343-344	1.10		13.50	11.90	0.19	0.46
344-345	1.60	0.84	14.1	8.93	0.62	0.80
348-349	1.05		1.50	0.05	0.25	0.21
349-350	1.48	0.92	20.4	17.6	0.68	0.18
350-351	1.10		24.00	8.78	0.10	0.23
351-352		0.46	21.3	11.6	0.16	0.23
364-365	2.0		18.90	7.80	0.39	0.62

TABLE B-4 DUAL-MEDIA FILTERS EFFLUENT, COMPOSITE SAMPLES, PART 1 (continued)

24 hour composite samples, results in mg/1.

Day	Total Phosphorus as P	Ortho Phosphate Filtrate as P	Total Kjeldahl as N	Ammonia Filtrate as N	Nitrite Filtrate as N	Nitrate Filtrate as N
1971						
4-5	1.65		16.80	13.80	0.19	0.28
5-6		0.88	6.75	6.6	0.40	0.44
6-7	0.15		15.00	7.30	0.32	0.65
7-8	1.65	0.67	14.4	9.15	0.84	0.44
11-12					0.15	0.55
12-13	2.0	0.40	8.4	3.68	0.19	0.75
13-14	0.40		7.20	4.00	0.22	0.70
14-15	0.24	0.18	6.0	5.8	0.10	0.14
48-49	1.30	1.20	17.80	13.50	0.12	0.80
49-50	0.98	0.94	8.7	5.5	0.15	4.0
53-54	0.77		12.6	5.30	0.13	0.70
54-55	0.67	0.77	13.2	9.6	0.16	1.0
55-56	0.48		11.7	8.1	0.15	0.95
56-57	0.77	0.66	4.6	4.2	0.16	1.10
60-61	1.90		8.4	5.5	0.18	1.3
61-62	1.6	1.5	8.7	4.1	0.31	1.6
62-63	1.55		8.4	2.2	0.17	1.4
63-64	1.50	1.40	7.8	1.35	0.10	1.70
68-69	2.0	1.90	3.3	2.2	0.10	1.70
70-71	1.10	0.94	4.8	3.4	0.15	2.0
74-75	2.2		3.30	1.80	0.12	1.7
75-76	2.0	1.90	4.8	0.40	0.10	1.9
76-77	1.95		4.50	0.72	0.13	1.6
77-78	1.9	0.98	3.3	1.2	0.09	1.6
81-82						
82-83	2.0	1.9	8.4	0.76	0.22	1.6
83-84	1.15		1.5	1.20	0.36	1.9
84-85	2.0	2.0	5.1	1.58	0.15	2.4
88-89						
89-90	1.35	1.25	4.5	2.7	.80	1.5

TABLE B-4 DUAL-MEDIA FILTERS EFFLUENT, COMPOSITE SAMPLES, PART 1 (continued)

24 hour composite samples, results in mg/l.

Day	Total Phosphorus as P	Ortho Phosphate Filtrate as P	Total Kjeldahl as N	Ammonia Filtrate as N	Nitrite Filtrate as N	Nitrate Filtrate as N
1971						
90-91						
95-96						
96-97	2.2	2.2	17.6	6.79	0.44	1.50
97-98						1.5
98-99	0.84	0.81	4.34	3.54	0.36	1.40
102-103						
103-104	2.0	2.0	5.78	0.51	0.25	1.6
104-105	2.2	2.2	5.78	4.41	0.46	1.1
105-106	2.2	2.20	10.98	1.25	0.40	1.9
109-110			3.30	1.15	0.39	1.4
110-111	2.3	2.2	9.3	1.40	0.46	1.9
111-112	2.25	2.15	6.60	2.50	0.66	2.2
112-113	3.40	3.20	7.2	3.53	0.28	1.5
116-117	2.2	2.2	5.40	2.55	0.05	1.4
118-119						
119-120	2.3	2.2				1.6
123-124	0.86	0.82			0.18	1.4
124-125	1.13	1.05	1.21	0.82	0	1.4
125-126	1.20	1.15	11.50	1.10	0.02	1.2
126-127	1.25	1.25	3.02	1.0	0.16	1.7
130-131		1.23				0.50
131-132	2.2	2.0	3.9	0.05	0.06	1.5
132-133						
133-134	2.2	2.0	2.11	0.10	0.09	1.3
137-138		2.1			0.054	0.85
139-140	3.0	2.70			0.32	1.4
140-141	1.85	1.85			0.02	1.3
144-145	1.15	0.88			0.044	1.5
145-146	1.45	1.28	3.35	0.48	0.08	1.4
146-147	2.30	2.20	5.58	3.10	0.54	1.2

TABLE B-4 DUAL-MEDIA FILTERS EFFLUENT, COMPOSITE SAMPLES, PART 1 (continued)

24 hour composite samples, results in mg/l.

Day	Total Phosphorus as P	Ortho Phosphate Filtrate as P	Total Kjeldahl as N	Ammonia Filtrate as N	Nitrite Filtrate as N	Nitrate Filtrate as N
1971						
147-148	1.30	0.85	4.09	0.42	0.54	1.5
151-152	0.38	0.35			0.07	1.50
152-153	0.77	0.71	1.86	0.37	0.04	1.60
153-154	0.77	0.72	2.98	0.10	0.04	1.70
154-155	0.51	0.49	2.98	0.22	0.17	1.7
158-159	0.33	0.23	2.61	0.115	0.26	1.70
159-160	0.18	0.12	1.86	0.35	0.07	1.60
160-161						
161-162	0.29	0.24	1.49	0.42	0.08	1.7
165-166	0.40	0.40	13.77	13.49	0.74	0.75
166-167	0.37	0.36	12.3	6.5	0.94	0.72
167-168	0.35	0.23	14.5	6.80	0.37	0.80
168-169	1.85	1.85	7.4	2.45	0.40	1.10
172-173	0.34	0.23	7.82	7.30	0.26	
173-174	0.24	0.17	10.0	7.50	0.15	0.54
174-175	0.42	0.33	19.40	8.80	0.11	0.74
175-176	0.48	0.27	11.91	10.70	0.18	1.60
179-180	0.18	0.10	9.40	6.80	0.24	0.98
180-181	0.37	0.19	7.2	0.85	0.62	0.60
181-182	0.72	0.18	12.10	4.30	0.21	2.00
182-183	0.72	0.61	3.77	0.72	0.30	1.75
187-188	0.24	0.18	3.77	1.13	0.04	2.0
189-190	1.7	0.27	0.75	0.05	0.48	0.82
194-195	1.10	0.34	1.51	0.22	0.16	1.10
196-197	0.52	0.33	1.51	0.72	0.40	1.30
210-211	1.4	0.72	6.32	5.2	0.27	0.54
215-216	1.50	1.30	3.35	0.08	0.52	0.75
217-218		0.03	1.12	0.115	0.67	0.95
222-223	0.16	0.14	8.53	7.60	0.25	0.30
224-225	0.28	0.09	4.26	1.48	0.35	0.25

TABLE B-4 DUAL-MEDIA FILTERS EFFLUENT, COMPOSITE SAMPLES, PART 2

24 hour composite samples, results in mg/l.

Day	pH	Alkalinity as $CaCO_3$	Total Hardness as $CaCO_3$	Calcium Filtrate as Ca	Magnesium Filtrate as Mg	Turbidity units
1970						
145-146	7.2	118	342	105.7	19.0	0.8
146-147	7.2					0.5
147-148	8.8	134	380	115	22.9	1.0
153-154	8.0					1.0
154-155	7.0	138	410	108	33.1	1.6
155-156	6.8					1.0
159-160	7.5	138	376	131.4	11.7	0.5
160-161	6.9					0.6
162-163	6.9					0.5
168-169	7.3	182	356	103	23.9	1.0
169-170	8.3					0.75
173-174	8.4	163	302	112.1	5.4	0.9
174-175	7.1					0.8
175-176	7.2	110	314	107.3	11.2	0.5
176-177	7.7					0.7
180-181	7.4	175	365	123.4	14.1	0.8
181-182	7.1					
187-188	7.4	180	392	101	34.1	0.7
188-189	7.3					0.85
189-190	9.3	143	330	109.7	13.6	1.4
190-191						0.70
194-195	7.2					1.10
195-196	6.6	111	368	101	28.2	0.9
196-197	6.8					1.30
197-198	7.4	126	330	109.7	13.6	0.9
201-202	8.4		322	116.9	7.3	1.2
202-203	7.4	91	310	102.5	13.1	1.0
203-204	7.2					0.5
204-205	7.1	97	364	96.9	29.7	1.5
208-209	7.5		390	140.2	9.74	0.85

TABLE B-4 DUAL-MEDIA FILTERS EFFLUENT, COMPOSITE SAMPLES, PART 2 (continued)

24 hour composite samples, results in mg/l.

Day	pH	Alkalinity as $CaCO_3$	Total Hardness as $GaCO_3$	Calcium Filtrate as Ca	Magnesium Filtrate as Mg	Turbidity units
1970						
209-210	9.0	136	374	111	23.4	1.5
211-212	7.3	136	388	102	32.1	1.5
215-216	7.7		412	105.0	36.5	0.90
216-217	7.2	163	384	98.5	33.6	3.0
217-218	7.2					1.7
218-219	7.2		380	96.9	33.6	7.0
222-223	7.2	137	364	111.3	20.94	1.0
223-224	7.0	111	318	96.9	18.5	1.0
224-225	7.1	104	324	97.7	19.48	0.8
225-226	7.1	108	308	95.3	17.0	0.9
229-230	7.5	104	334	108.1	15.58	0.7
230-231	7.4	171	314	88.9	22.4	1.6
231-232	7.7	274	372	80.1	41.9	6.5
232-233	7.6	173		106		2.3
236-237	7.5	105.2	370	129	11.69	0.7
237-238	8.1	144	350	109.7	18.5	0.56
238-239	7.5	126.3	370	100.9	28.7	0.30
239-240	7.3	109	322	102.5	16.1	0.6
316-317	7.3	222	380	115.3	22.4	2.3
341-342	8.5	225	346	92.9	27.8	3.5
342-343	9.0	221	304	81.7	24.3	3.5
343-344	9.5	182	290	97.7	11.2	5.0
344-345	9.4	217	336	110	15.1	5.0
348-349	9.4	215				8.0
349-350	9.3	266	320	90.5	22.9	6.0
350-351	9.1	286	358	93.7	30.2	6.0
351-352	9.4	258	338	92.1	26.3	3.0
364-365	9.0	275	428	107.3	39.0	

TABLE B-4 DUAL-MEDIA FILTERS EFFLUENT, COMPOSITE SAMPLES, PART 2 (continued)

24 hour composite samples, results in mg/l.

Day	pH	Alkalinity as $CaCO_3$	Total Hardness as $CaCO_3$	Calcium Filtrate as Ca	Magnesium Filtrate as Mg	Turbidity units
1971						
4-5	8.9	229.2	372	106.5	25.8	3.7
5-6	8.1	186	376	116.1	20.9	3.4
6-7	8.6	142.4	350	108.9	19.0	2.2
7-8	8.5	224	384	96.9	34.6	10
11-12	8.6	203	424	121.8	29.2	3.6
12-13	8.0	209	426	149.8	12.7	1.5
13-14	7.7	142.2	390	120.1	21.9	2.7
14-15	8.0	138	360	108.1	21.9	3
48-49	7.6	273.0	382	96.1	34.6	3.5
49-50	7.6	253	378	108.1	26.3	2
53-54	7.6	206.5	410	113.7	30.68	4.4
54-55	7.4	241	390	108.9	28.7	2.5
55-56	7.6	229.1	386	101.1	33.1	2.9
56-57	7.7	229	386	105.7	29.7	4.2
60-61	7.6	244.9	450	119.3	37.0	3.8
61-62	7.7	230	438	129.8	27.8	3.5
62-63	7.8	213.2	450	121.6	35.6	6.4
63-64	8.0	194.6	458	136.2	28.7	2
68-69	7.6	195	432	111.3	37.5	3
70-71	8.2	209	440	116.9	36.0	7
74-75	7.8	206.5	444	120.9	34.58	2.0
75-76	8.0	193	438	126.6	29.7	2
76-77	7.7	198.6	452	124.0	34.6	2.0
77-78	8.0	208	466	129.0	35.1	2
81-82	7.7	233				2.7
82-83	7.9	205.2	460	125.0	36.0	2
83-84	7.6	206.5	478	127.4	39.0	2.2
84-85	7.8	214	466	127.4	36.0	1.8
88-89	7.8	242.3				2.8
89-90	8.1	193	418	109	35.6	2.0

TABLE B-4 DUAL-MEDIA FILTERS EFFLUENT, COMPOSITE SAMPLES, PART 2 (continued)

24 hour composite samples, results in mg/l.

Day	pH	Alkalinity as $CaCO_3$	Total Hardness as $CaCO_3$	Calcium Filtrate as Ca	Magnesium Filtrate as Mg	Turbidity units
1971						
90-91	7.5	165.5	422	112.1	34.6	1.0
95-96	7.5	148.8				3.2
96-97	7.5	138	426	112.1	35.6	2
97-98	7.5	140.4	428	110.5	37.0	1.7
98-99	7.9	151	438	112.9	38.0	2.7
102-103	8.4	172.8				3.3
103-104	8.3	193.2	444	117.7	36.5	2.5
104-105	8.0	170.4	440	119.3	34.6	3.3
105-106	8.0	158.4	438	120.1	33.6	2.5
109-110	7.7	200	448	109.0	42.9	2.7
110-111	8.0	201	454	111	43.3	2.0
111-112	7.9	201	468		39.0	3.0
112-113	7.6	232	454	115.3	40.4	7.0
116-117	7.6	254.0	428	111.3	36.5	4.8
118-119	7.1					
119-120	7.4		432	108.9	39.0	3.3
123-124	7.8	181.4	422	111.3	35.1	
124-125	8.0	166.1	406	109.7	32.1	2.0
125-126	7.8	180.6	438	116.9	35.6	2.0
126-127	8.0	195.1	446	120.1	35.6	2.0
130-131	7.3		438	122.6	32.1	1.8
131-132	7.8	216	426	109.7	37.0	3.2
132-133	7.9					1.1
133-134	7.9	200.3	434	116.1	35.1	2.0
137-138	7.8	195.0	428	116.1	33.6	1.5
139-140	7.9	212.2	438	120.9	33.1	1.4
140-141	8.0	195.1	426	109.7	37.0	2.2
144-145	7.6	149.9	388	99.3	34.1	1.5
145-146	7.7	179.2	404	97.7	39.0	2
146-147	7.7	175.9	392	103.3	32.6	2.3

TABLE B-4 DUAL-MEDIA FILTERS EFFLUENT, COMPOSITE SAMPLES, PART 2 (continued)

24 hour composite samples, results in mg/l.

Day	pH	Alkalinity as $CaCO_3$	Total Hardness as $CaCO_3$	Calcium Filtrate as Ca	Magnesium Filtrate as Mg	Turbidity units
1971						
147-148	9.3	118.9	372	120.1	17.53	11.0
151-152	8.4	162.6	418	160.2	4.4	3.5
152-153	8.1	166.2	394	150.6	4.38	1.5
153-154	7.9	138.5	378	141.8	5.8	1.7
154-155	8.6	78.2	382	144.2	5.36	3.0
158-159	8.3	149.8	388	147.4	4.87	1.4
159-160	8.5	99.4	370	146.6	0.97	4.0
160-161	8.3					
161-162	8.0	140.1	404	157.8	2.43	2.0
165-166	8.3	180.8	320	108.1	12.2	1.8
166-167	8.2	169.4	332	103.3	18.0	4.0
167-168	8.4	151.3	326	97.72	19.97	2.0
168-169	8.0	158.0	376	118.5	19.48	2.5
172-173	7.8	169.4	332	115.3	10.7	2.3
173-174	8.3	122.2	290	98.5	10.71	3.0
174-175	8.6	152.6	286	92.92	13.15	2.0
175-176	8.1	138.5	288	98.5	10.23	4.5
179-180	7.7	142.8	320	122.6	3.41	1.4
180-181	7.6	126.4	330	121.0	6.8	1.4
181-182	7.9	131.3	342	124.2	7.8	1.4
182-183	8.0	155.9	374	84.9	39.4	3.0
187-188	8.4	98.5	344	136.2	0.97	3.0
189-190	10.1	27.2	320	127.4	0.49	2.0
194-195	8.1	154.3	386	150.6	2.43	6.0
196-197	7.9	123.1	342	130.6	3.90	3.0
210-211	7.7	170.0	366	107.3	23.86	5.0
215-216	8.0	140.6	362	138.6	3.90	2.0
217-218	8.0	107.9	334	127.4	3.90	2.0
222-223	8.4	127.7	286	96.1	12.20	3.0
224-225	8.4	104.5	276	89.7	12.66	2.0

TABLE B-4 DUAL-MEDIA FILTERS EFFLUENT, COMPOSITE SAMPLES, PART 3

24 hour composite samples, results in mg/l.

Day	Suspended Solids	COD	COD Filtrate	BOD	Color units	Methylene Blue Active Substances
1970						
145-146	29					
146-147		26.3	75.2			
147-148	25			1.49	20	
153-154		21.6	18.6			
154-155	18			1.49	5	
155-156		47.9	26.0		10	
159-160	15					
160-161		30.2	26.8			
162-163		37.6	27.6		15	
168-169	8			5.15	25	
169-170		53.2	50.1		25	
173-174	23					
174-175		57.8	51.9			
175-176	23				20	
176-177		50.6	47.6		25	
180-181	29					
181-182		39.2	36.0			
187-188	17					
188-189		28.7	25.3			
189-190	28	28.2			35	
190-191		18.0	18.0		20	
194-195		30.7	30.0			
195-196	22	36.8				
196-197		37.0	36.0		20	
197-198	8	53.2			20	
201-202		32.7	30.6			
202-203	12	31.3				
203-204		23.7	20.4			
204-205	14	25.9		0.66	15	
208-209		25.7	24.8			

TABLE B-4 DUAL-MEDIA FILTERS EFFLUENT, COMPOSITE SAMPLES, PART 3 (continued)

24 hour composite samples, results in mg/l.

Day	Suspended Solids	COD	COD Filtrate	BOD	Color units	Methylene Blue Active Substances
1970						
209-210	6	25.4		0.5		
211-212	11	22.7		1.00	35	
215-216		27.5	22.9		40	
216-217	5	27.1		1.63		
217-218		23.1	21.6			
218-219	10	35.8		5.81	25	
222-223		36.7	29.2		25	
223-224	7	23.4		0.8		
224-225		26.7	26.5		20	
225-226	8	27.7		0	20	
229-230		18.3	18.3		25	
230-231	7	32.3			25	
231-232		59.8	55.0		35	
232-233	10	27.8		5.0	20	
236-237		20.8	20.8		20	
237-238	8	19.2			15	
238-239		21.2	18.9		15	
239-240	6	15.6		0.83	20	
316-317	32	25.8				
341-342	70	37.3			30	
342-343	24	32.2		5.2	30	1.2
343-344		38.1			25	
344-345	99	37.3				
348-349	52	30.8				
349-350	45	49.3		7.2	45	2.2
350-351	37	42.2			45	
351-352	12	40.8				
364-365		46.1				

TABLE B-4 DUAL-MEDIA FILTERS EFFLUENT, COMPOSITE SAMPLES, PART 3 (continued)

24 hour composite samples, results in mg/l.

Day	Suspended Solids	COD	COD Filtrate	BOD	Color units	Methylene Blue Active Substances
1971						
4-5		55.2			25	
5-6	27	49.5		2.67	20	0.20
6-7		37.3			15	
7-8	18	36.0				
11-12	25	35.9			20	
12-13	22	31.6		3.34	20	0.23
13-14		37.9			25	
14-15	22	39.6				
48-49		48.6		9.6	20	
49-50	29	31.5				
53-54		34.1			30	
54-55	13	31.0		20.0	20	0.15
55-56		34.6		22.8	25	
56-57	24	34.3				
60-61		37.5			30	
61-62	12	34.5		18.4	40	0.20
62-63		44.8		12.4	30	
63-64	8	42.6				
68-69	10	31.6		12.0	30	0.15
70-71	15	37.1				
74-75		25.8			20	
75-76	30	33.1			25	0.13
76-77		28.2		2.8	30	
77-78	24	34.6			30	
81-82	14	36.9			30	
82-83	20	35.7		8.0	30	0.20
83-84		26.6			45	
84-85	30	28.1			30	
88-89	21	28.0			20	
89-90	30	31.3		14.8	30	0.027

TABLE B-4 DUAL-MEDIA FILTERS EFFLUENT, COMPOSITE SAMPLES, PART 3 (continued)

24 hour composite samples, results in mg/l.

Day	Suspended Solids	COD	COD Filtrate	BOD	Color units	Methylene Blue Active Substances
1971						
90-91	18	37.8			30	
95-96	23	29.0			35	
96-97	17	27.8		3.6	25	0.20
97-98	30	25.3			20	
98-99	16	27.7				
102-103	26	31.2			40	
103-104	31	22.4		2.4	40	0.03
104-105	27	33.6			35	
105-106	18	39.6				
109-110	30	25.6			35	
110-111	21	20.7		0.80	35	0.026
111-112	29	37.2		3.2	30	
112-113	37	43.3				
116-117	31	27.3			30	
118-119		43.0				
119-120	2					
123-124		18.0				
124-125	27	31.6			25	0.04
125-126	25	31.5			30	
126-127	24	25.5				
130-131	17	28.3			30	
131-132	27	26.3		4.4	25	0.03
132-133	25	21.2			30	
133-134	26	23.1				
137-138	22	30.3			25	
139-140	24	28.5			25	
140-141	22	22.9				
144-145	35	33.5			25	
145-146	28	17.6		0	25	0.04
146-147	21	26.6			30	

TABLE B-4 DUAL-MEDIA FILTERS EFFLUENT, COMPOSITE SAMPLES, PART 3 (continued)

24 hour composite samples, results in mg/1.

Day	Suspended Solids	COD	COD Filtrate	BOD	Color units	Methylene Blue Active Substances
1971						
147-148	47	24.4				
151-152	38	19.1			20	
152-153	27	18.3		0.84	15	0.03
153-154	33	18.2			15	
154-155	32	27.6				
158-159	27	19.4			10	
159-160	43	21.3		0.4	15	0.02
160-161		24.5				
161-162	26	25.0				
165-166	34	21.6			20	
166-167	37	26.1		7.6	20	0.20
167-168	41	23.2			15	
168-169	33	16.7				
172-173	31	24.7			15	
173-174	32	33.1			20	0.20
174-175	24	25.3			20	
175-176	24	29.9		15.6		
179-180	29	22.6			15	
180-181	19	17.6			15	0.20
181-182	26	20.2			25	
182-183	35	24.6		6.8		
187-188	30	16.1		2.8	15	0.20
189-190	26	40.0				
194-195	29	22.6		5.20	10	0.20
196-197	24	19.0				
210-211	24	27.7				
215-216	26	23.6		8.4	15	0.45
217-218	17	20.7				
222-223	34	24.8		9.2	15	0.40
224-225	29	22.7				

TABLE B-5 GRAB SAMPLES TAKEN AFTER COMPOSITE PROGRAM ENDED, PART 1

results in mg/1.

		REACTOR CLARIFIER INFLUENT							
Day	Time	Total Phosphorus as P	Ortho Phosphate Filtrate as P	pH	Alkalinity as $CaCO_3$	Turbidity units	Suspended Solids	COD	Color units
235	7:45	11.4	11.0	7.1	355				
236	7:45	13.4	14.4	6.8	347		30.0	76.5	35
237	7:45	10.6	10.8	6.8	362	9.0			
238	8:00	10.4	11.4	7.5	264	8.0	29.0	56.5	40
239	8:00		10.4	7.0	258	9.0			
242	8:45	11.0	10.4	7.4	251	6.2	25.0		35
243	8:30	13.0	13.0	7.2	231	6.2		48.4	
244	8:30	10.8	10.4	7.6	197	8.4			
245	8:30	11.0	12.6	7.8	207	9.0	28.[illegible]		40
246	8:30	10.4	10.4	7.3	207	7.7		55.2	
250	8:30	8.6	8.8	7.4	199	6.4	17.0		40
251	8:30	7.6	9.4	7.3	184	4.7		61.1	
252	8:30	9.0	7.2	7.6	189	7.3	23.0		45
253		9.8	9.8	7.2	193	8.8		64.8	
256	8:30	10.4	9.4	7.3	173	11.2	42.0		45
257	8:30	11.0	11.6	7.3	182	8.3		76	
258	8:30	8.6	8.6	7.4		8.5	46.0		50
259	8:30	7.6	6.8	6.8	137	12.0			
260	8:00	10.4	9.4	6.7	138	14.0		76.0	
263									
264	8:30	17.4	17.4	7.5	184	8.5	38		50
265	8:30			7.5	166	12.5		77.0	
266	8:30	13.6	11.6	7.4	203	14.0	78.0		60
267	8:30	12.0	11.0	7.6	259	14.0			
270	8:30	16.8	12.8	7.6	173	9.2	42.0		60
271	8:30	13.6	19.6	7.3	159	9.0		87	
272	8:30	9.4	9.0	7.1					

TABLE B-5 GRAB SAMPLES TAKEN AFTER COMPOSITE PROGRAM ENDED, PART 2

results in mg/1.

Day	REACTOR-CLARIFIER EFFLUENT Total Phosphorus as P	Ortho Phosphorus Filtrate as P	pH	Alkalinity as $CaCO_3$	Turbidity units	Suspended Solids	COD	Color units	FILTER INFLUENT pH	FILTER EFFLUENT Total Phosphorus as P	Ortho Phosphate Filtrate as P
235	.35	.18	10.1	221					8.7		
236	.38	.26	11.0	210		16.0	37.0	25			
237	.21	.069	10.8	280					8.7		
238	.34	.15	10.6	207	6.7	16.0	29.9	25	8.8		
239	.19	.083	10.0	199	5.5				9.1		
242	.22	.023	10.5	215	4.7	10.0		15	8.6		
243	.096	.029	10.9	205	4.0		30.7		8.4		
244	.088	.043	11.4	396	5.7				8.3		
245	.051	.074	11.5	199	4.8	23.0		15	8.8		
246	.087	.029	10.9	189	2.2		32.3		9.0	.22	.10
250	.064	.026	11.5	272	2.7	23.0		20	8.9	.052	.035
251	.037	.031	11.1	178	2.8		37.4		8.9	.075	.067
252	.13	019	10.8	156	2.9	16.0		25	9.4	.16	.097
253	.13	.022	10.9	160	3.5		41.0		9.4	.20	.026
256	.38	.067	10.0	174	7.0	12.0		20	8.8	.55	.039
257	.061	.019	11.0	171	3.0		39		8.6	.45	.10
258	.046	.019	11.4		2.4	16.0		25	8.8	.15	.13
259	.042	.019	10.9	203	2.8				8.9	.075	.04
260	.10	.019	10.8	207	2.9		34.0		8.9	.046	.025
264	.086	.036	11.2	222	2.8	18		35	8.8	.067	.028
265			11.0	170	3.2		38.0		9.0	.11	.064
266	.083	.027	11.1	246	4.6	19.5		35	9.1	.14	.054
267	.19	.019	11.0	195	4.5				9.1	.60	.25
270	.26	.019	10.8	170	6.5	16.5		30	8.5	.53	.11
271	.052	.026	11.4	262	5.8		55		9.0	.06	.15
272	.031	.019	11.4							.052	.028

APPENDIX C

TABLE C-1 HEAD AND TURBIDITY OBSERVATIONS ON FILTERS.

Gallons Cumulative	Increase In Head-feet	Product Turbidity
Run 37		
0	0	---
19,105	.1	1.6
43,151	.5	---
63,464	1.0	1.3
83,997	1.4	---
108,921	2.1	1.6
132,858	2.9	---
151,414	3.5	1.5
182,707	4.6	---
202,141	5.1	1.7
Run 38		
0	0	1.6
23,387	.3	---
46,006	.5	1.3
73,126	1.1	---
94,428	1.4	1.7
117,376	1.9	---
144,167	2.7	1.3
165,468	3.3	---
191,271	4.1	1.6
211,914	4.7	---
Run 39		
0	0	---
22,509	.3	1.6
47,872	.6	---
71,919	1.0	1.6
95,526	1.4	---
119,352	2.0	1.9
143,398	2.6	---
164,041	3.4	1.8
189,514	4.7	---
209,169	5.1	1.7

Gallons Cumulative	Increase In Head-feet	Product Turbidity
Run 40		
0	0	1.5
22,509	.1	---
48,312	.2	1.5
71,699	1.2	---
93,439	1.7	1.2
116,497	2.3	---
140,434	3.5	1.3
163,931	4.0	---
185,013	4.7	1.6
Run 41		
0	0	1.4
24,595	.4	---
59,731	1.0	1.4
87,730	1.6	---
127,807	3.1	1.3
144,936	3.6	---
162,833	4.2	1.3
202,471	5.4	1.4

APPENDIX D

TABLE D-1 CHEMICAL TESTS ON STUDY POND TWO, PART 1.

Date	Day of Year	Ortho-phosphate Filtrate mg/1-P	Total Phosphate mg/1-P	Ammonia Filtrate mg/1-N	Nitrite Filtrate mg/1-N	Nitrate Filtrate mg/1-N	Total Kjeldahl mg/1-N
Nov. 16, '70	320	0.96	0.98	9.38	0.76	0.50	13.2
Nov. 30	334	8.8	12.0	3.0	2.0	0.85	6.0
Dec. 7	341	---	---	---	---	---	---
Dec. 14	348	11.2	12.0	9.6	0.39	0.38	21.9
Dec. 28	362	5.80	6.60	5.85	2.1	0.35	9.3
Jan. 11, '71	11	6.80	7.20	3.68	3.0	0.80	10.5
Jan. 25	25	8.0	9.0	6.75	2.50	0.62	12.9
Feb. 8	39	3.6	5.0	5.5	2.0	1.0	14.1
Feb. 22	53	2.20	---	7.8	---	0.90	---
March 8	67	0.35	1.00	0.82	0.16	1.60	2.9
March 22	81	3.60	4.80	1.80	0.90	1.60	10.2
April 5	95	1.20	1.76	0.27	0.46	1.60	0.78
April 19	109	3.20	3.80	0.08	0.34	1.0	6.36
May 3	123	1.23	24.0	0.12	0.34	1.10	8.4
May 17	137	1.40	3.8	0.17	0.26	0.80	4.83
June 7	158	8.4	10.0	.92	.32	.90	8.19
June 21	172	3.40	5.80	2.90	0.44	3.5	8.19
July 12	193	16.0	16.4	0.08	0.19	2.20	6.03
July 26	207	1.76	4.60	0.22	0.13	0.60	4.52
Aug. 9	221	1.60	3.8	2.20	0.29	0.22	7.81

TABLE D-1 CHEMICAL TESTS ON STUDY POND TWO, PART 2.

Day of Year	pH	Suspended Solids mg/1	Turbidity JTU	COD mg/1	COD Filtrate mg/1	Color	Temp. °C	Dissolved Oxygen mg/1	Alkalinity mg/1
320	7.5	27	6.7	50.4	40.0	40	16	10.6	222.0
334	8.2	71	14	72.0	44.0	60	15	8.7	152.0
341	8.6	---	---	---	---	60	---	---	---
348	7.6	53	8	76.0	49.3	40	15	9.6	243.0
362	7.6	46	10	51.4	31.8	35	13	13.5	263.0
11	8.3	50	12	75.8	52.1	60	12	15.0+	224.0
25	7.9	49	12	86.6	51.5	70+	14	15+	260.0
39	8.7	96	12	100.0	51.0	70+	18	15+	217.0
53	7.8	26	6	58.9	---	40	16	8.3	278.0
67	8.2	34	17	19.7	10.7	30	17	13.4	109.0
81	7.8	87	22.0	67.9	40.0	25	18	13.4	169.0
95	9.5	133	19	73.6	42.0	40	20	13.8	67.9
109	9.4	71	22.5	61.6	37.6	30	16	12.6	84.0
123	9.6	96	20	76.8	49.7	40	18	10.8	2.6
137	9.1	63	22	65.7	32.4	30	19	8.6	83.0
158	8.0	89	8.0	40.4	33.6	25	23	9.0	189.0
172	8.2	52	17.0	48.8	42.8	25	22	8.1	221.5
193	9.2	86	27.0	69.5	38.4	40	24	7.8	117.2
207	9.4	105	27	79.2	44.6	40	23	7.6	84.0
221	9.1	90	22	76.4	56.6	40	24	8.9	118.8

TABLE D-2 CHEMICAL TESTS ON STUDY POND THREE, PART 1.

Date	Day of Year	Ortho-phosphate Filtrate mg/1-P	Total Phosphate mg/1-P	Ammonia Filtrate mg/1-N	Nitrite Filtrate mg/1-N	Nitrate Filtrate mg/1-N	Total Kjeldahl mg/1-N
Nov. 16, '70	320	0.98	1.0	4.70	0.46	0.65	5.7
Nov. 30	334	0.56	0.68	2.18	2.2	0.83	3.9
Dec. 7	341	---	---	---	---	---	---
Dec. 14	348	0.68	0.70	6.6	0.54	0.65	10.2
Dec. 28	362	0.10	0.46	5.40	0.66	0.37	6.0
Jan. 11, '71	11	0.34	0.39	3.0	0.54	0.40	9.6
Jan. 25	25	0.50	0.66	5.33	0.21	1.50	10.5
Feb. 8	39	0.34	0.70	2.9	0.49	1.2	3.01
Feb. 22	53	1.55	---	5.2	---	1.0	---
March 8	67	0.88	1.65	0.25	0.16	2.0	1.5
March 22	81	0.74	1.25	1.55	0.15	1.80	8.7
April 5	95	0.28	0.62	2.2	0.50	1.60	3.73
April 19	109	0.80	1.55	0.30	0.32	1.4	4.62
May 3	123	0.19	0.88	0.07	0.36	1.30	7.5
May 17	137	0.42	1.17	0.13	0.37	0.85	4.53
June 7	158	0.24	0.63	0.01	0.50	1.0	6.33
June 21	172	0.13	0.52	1.55	0.25	0.15	2.61
July 12	193	0.88	1.35	0.86	0.14	1.10	1.89
July 26	207	0.23	0.79	0.05	0.14	0.60	12.82
Aug. 9	221	0.05	0.40	0.42	0.28	0.50	3.72

TABLE D-2 CHEMICAL TESTS ON STUDY POND THREE, PART 2.

Day of Year	pH	Suspended Solids mg/1	Turbidity JTU	COD mg/1	COD Filtrate mg/1	Color	Temp. °C	Dissolved Oxygen mg/1	Alkalinity mg/1
320	8.6	12	2.2	30.0	27.6	20	15	11.2	223
334	9.7	25	3	30.4	28.0	20	15	8.5	128
341	9.3	---	---	---	---	25	---	---	---
348	9.2	35	5.8	47.9	38.2	25	15	10.2	185
362	9.3	41	12	41.0	28.5	25	12	11.8	207
11	9.4	27	3	43.9	34.2	25	12	15+	167
25	9.3	28	8	70.8	49.9	70+	14	15+	154
39	9.8	57	12	68.3	45.6	60	18	15+	165
53	8.1	27	11	60.7	---	45	16	6.6	212
67	9.4	30	13	32.8	28.3	50	16	17.1	197
81	8.6	78	15.0	59.1	40.9	45	19	14.6	188
95	10.0	79	12	78.4	44.0	35	19	14.8	28
109	9.7	67	12	52.0	27.0	25	16	10.6	77.7
123	10.0	82	15	69.1	41.2	40	18	10.2	76.0
137	9.8	50	13	69.0	39.1	30	19	8.8	74.5
158	10.0	95	13	66.0	38.0	45	24	15.0+	56.2
172	9.4	59	10	58.6	39.3	30	20	8.7	26.1
193	9.2	46	11	47.7	38.4	20	25	7.2	53.7
207	9.4	54	6	32.2	27.5	25	23	7.4	43.6
221	9.0	47	12	46.6	36.1	40	25	9.2	21.8

TABLE D-3 DISSOLVED OXYGEN TESTS ON THE STUDY PONDS.

Time & Date	Pond Two D.O., mg/l	Pond Two Temp., °C	Pond Three D.O., mg/l	Pond Three Temp., °C
1500, Aug. 19, 71	10.2	30	9.8	30
1700	10.1	27	9.6	27
1900	10.3	26	9.9	26
2100	8.0	26	7.1	26
2300	6.8	25.5	6.6	25.5
0100, Aug. 20, 71	6.5	25	5.9	25
0300	4.2	25	4.3	25
0500	2.8	24.5	3.3	24.5
0700	2.6	24.25	3.4	24.5
0900	5.7	25	5.3	25
1100	9.5	27.5	5.9	27
1300	9.7	30.5	8.5	29.5
1500	9.6	30	9.2	28